

Faculty of Education



ESRC linked +3 Research Studentship (full-time PhD)

Effecting Principled Improvement in STEM Education (*epiSTEMe*): Student Engagement and Learning in Early Secondary-School Physical Science and Mathematics

Applications are invited for an Economic and Social Research Council [ESRC] +3 Research Studentship to undertake a PhD study on some topic linked to the work of the *Effecting Principled Improvement in STEM Education* (*epiSTEMe*) project. This project forms part of the ESRC's Targeted Initiative on Science and Mathematics Education. It provides a unique opportunity to work as a doctoral student with leading researchers in the field, in Cambridge and the other participating institutions.

A Research Studentship holder will work primarily on an independent study associated with the project, but will have opportunities for involvement in all aspects of the project's work relevant to supporting advanced research training and career development. Supervision will be provided by one or more of the project investigators: Professors Kenneth Ruthven, Christine Howe, Neil Mercer, and Dr Keith Taber. They, with Research Associates Dr Riikka Hofmann and Dr Stefanie Luthman, form the core research team for the project.

The University of Cambridge

The University of Cambridge is one of the oldest universities in the world and one of the largest in the United Kingdom. Its reputation for outstanding academic achievement is known world-wide and reflects the intellectual achievement of its students, as well as the world-class original research carried out by the staff of the University and the Colleges.

The Faculty of Education

The Faculty constitutes one of the largest groups of educational researchers and teacher educators in the country. It has a diverse research profile, currently with annual grant expenditure of over £2.5 million, from a range of sponsors including the Research Councils and a wide range of government departments and national agencies active in Education. The Faculty has a varied teaching programme with full- and part-time courses for over 1600 postgraduate and undergraduate students undertaking a range of qualifications; PhD, MPhil, MEd, Advanced Certificate and Diplomas, BA in Education Studies. Further information about the Faculty is available at www.educ.cam.ac.uk.

The Faculty has five Academic Groups, including one in Science, Technology and Mathematics Education, and one in Psychology and Neuroscience in Education, each with over 20 academic and research staff members and running a range of specialist seminar series and graduate programmes. Information about the groups is available at <http://www.educ.cam.ac.uk/research/academicgroups/>.

The epiSTEMe Project

Many students in secondary school find physical science and mathematics uninteresting and difficult to learn with understanding. This leaves important gaps in their education and narrows the range of careers open to them. The *epiSTEMe* project will redesign key aspects of the teaching and learning of these subjects, devising a principled approach which is more effective in engaging students and guiding them towards understanding. Insights from several social scientific fields – concerned with conceptual growth, identity formation, classroom dialogue, collaborative learning, and relations between everyday and formal understanding – will guide the design of an intervention suitable for widespread use in normal school settings. This research project will explore students' reasoning in three complex domains that have considerable significance to theories of cognitive development, improve broader understanding of teaching and learning processes in science and mathematics, and generate tried-and-tested resources for training teachers and teaching students. Phase 1 will involve collaboration with teacher co-researchers from several schools to devise and pilot the intervention. In Phase 2, classroom implementation by the teacher co-researchers will be analysed, and the intervention refined accordingly. Phase 3 will evaluate repeated implementation by the teacher co-researchers, alongside initial implementation by teachers from a wider range of schools, compared to the established practice of a control group of teachers from similar schools.

The proposal accepted by the ESRC is provided in Appendix 1.

Starting Date

The studentship is available for up to 36 months. The successful candidate will commence study in January 2010, at the start of the University's Lent Term.

Terms and Conditions

This project-linked +3 Research Studentship is subject to the standard ESRC rules detailed in the Guidance Notes for Applicants available, with other relevant information, at <http://www.esrcsocietytoday.ac.uk/ESRCInfoCentre/opportunities/postgraduate/fundingopportunities/>.

Eligibility

Candidates must satisfy normal University and Faculty requirements for PhD study: information about these is available at <http://www.educ.cam.ac.uk/graduate/phd/index.html>. Any enquiries should be directed to Emma Rixon (er206@cam.ac.uk) in the Faculty's Higher Degrees office. Candidates must also meet normal ESRC requirements for studentship eligibility, detailed in its Guidance Notes for Applicants. Essentially, Research Studentship awards are restricted to those having a relevant connection with the United Kingdom or another European Union or European Economic Area country. Likewise, +3 awards are restricted to those who, on taking up the award, have successfully completed either an ESRC-approved research training course, or demonstrably equivalent training (Appendix 2 contains the relevant extracts from ESRC guidance).

Application Procedure

Candidates must apply in the normal way for admission to PhD study in the Faculty. Candidates should indicate in their applications that they wish to be considered for the *epiSTEMe*-linked studentship, and send a message to alert Emma Rixon (er206@cam.ac.uk) in the Faculty's Higher Degrees office. **Consideration of each individual application will start as soon as a complete submission has been made. Early application is encouraged to allow ESRC approval to be secured in time for a January start.**

Suitable Topics

The application procedure requires candidates to prepare an outline research proposal for their doctoral study.

The *epiSTEMe* project has been designed in the light of the following major research challenges identified by the Commissioning Panel for the ESRC Initiative:

- What are the key factors that shape patterns of participation, engagement and achievement in science and/or mathematics education by children and young people and what does this tell us about the kinds of intervention that are likely to have greatest impact on participation, engagement and achievement?
- What can we learn from the effectiveness of past and current interventions, initiatives and practice to inform the design and development of more effective interventions, initiatives and practice?
- How can research-informed approaches help to address some of the key challenges in enhancing participation, engagement and achievement in science/mathematics identified by recent research and reports?
- What specific new interventions or changes in policy or practice offer the greatest potential to improve participation, engagement and learning in science/mathematics and how could their potential effectiveness and feasibility be assessed more fully?

The overarching goal of the *epiSTEMe* project is to develop theoretically informed and practically effective means of improving student engagement and learning in physical science and mathematics during the early stages of secondary education, which are suitable for wide-scale implementation. The research process through which the project aims to achieve this goal has the following objectives:

- to develop a system of pedagogical principles which build on long-term efforts - notably in the USA- to formulate standards for science and mathematics education, explicitly grounding these in an integrative framework of key ideas from social scientific theory;
- to apply these principles to the design of a classroom intervention -suitable for wide-scale implementation- based on illustrative topic modules on proportionality, probability and electricity;
- to develop, pilot and validate a system of instruments to assess the effectiveness of the classroom intervention and its supporting topic modules in enhancing student attitude/engagement and achievement/learning;
- to pilot and refine the classroom intervention and its supporting topic modules, analysing the patterns of classroom activity and student learning associated with them;
- to analyse how characteristics of classroom dialogue and interaction are related to changes in student attitude/engagement and achievement/learning.

- to design a training programme -suitable for subsequent scaling-up of implementation of the intervention- to introduce teachers to the system of pedagogical principles informing the classroom intervention and its supporting topic modules;
- to pilot and refine this training programme;
- to evaluate the classroom intervention and its supporting topic modules summatively, across a substantial and varied sample of schools, including analysis of relative effectiveness for students of different socio-economic status, gender and ethnicity.
- to review, in the light of evaluations and analyses conducted during the project, the system of pedagogical principles and the integrative framework of key ideas from social scientific theory which underpin it.

Consideration will be given to research proposals on topics linked to any aspect of the project. Some examples of possible areas for research are as follows:

- approaches to designing curriculum-related problem-based activities which integrate mathematics and science;
- approaches to managing and coordinating group discussion and whole class teaching in secondary mathematics and/or science;
- the development of students' ideas about the character of mathematical and/or scientific knowledge and activity;
- the evolving curricular and pedagogical perspectives and practices of project teachers, and the factors shaping this evolution.

There is no suggestion that proposals on these particular topics will be favoured; they are intended only to illustrate that there is a wide range of potential topics that could be associated with the project.

Further informal enquiries, cognisant of the *epiSTEMe* plan, are welcome as to the suitability of any topic: these should be addressed, in the first instance, to Emma Rixon (er206@cam.ac.uk), who will then direct them to an appropriate member of the project team.

Appendix 1: Research proposal accepted by ESRC

Effecting Principled Improvement in STEM Education: Student Engagement and Learning in Early Secondary-School Physical Science and Mathematics

Investigators

Kenneth Ruthven, Christine Howe, Neil Mercer & Keith Taber
University of Cambridge Faculty of Education

Introduction

Our proposed research exemplifies an approach to effecting principled improvement in STEM education. It will develop theorised means of improving student engagement and learning in physical science and mathematics during the early stages of secondary education. We will derive promising principles from prior research and development, and apply these to design a classroom intervention (and associated teacher training) suitable for wide-scale implementation. We will not only evaluate this intervention but create and test integrative theory to explain its mechanisms.

We will draw particularly on long-term efforts in the USA to formulate *National Science Education Standards* (NAS, 1995) and *Principles and Standards for School Mathematics* (NCTM, 1989, 2000), and to operationalise these in ‘Standards-based curricula’ which foster coherent understanding of fundamental ideas and their relationships, help students to explore and make sense of the material that they are learning, and show that knowledge is a tool for solving problems (Trafton et al., 2001). We will take account of pedagogical principles common to several curricula judged ‘Exemplary’ by the Mathematics and Science Expert Panel of the US Department of Education, on the basis of evidence of effectiveness in multiple sites (on a large scale, in rural and urban locations, across US states) for multiple subpopulations (by age, gender, ethnicity, ability). A member of our team (Ruthven) has served on the Advisory Board for one of these curriculum projects since its inception, and has contact with others.

While the US ‘exemplary’ curricula are research-informed in being extensively evaluated (e.g. Reys et al., 2003; Riordan & Noyce, 2001), and in appealing to views of learning consonant with theoretical syntheses now available (e.g. Bransford et al., 2000; Kilpatrick et al., 2003), their design has been weakly framed in theoretical terms and their evaluation correspondingly restricted (Confrey, 2006; Harwell et al., 2007). The originality and significance of our proposal is in linking relevant social scientific theory to the operational design of subject curriculum and pedagogy. Our research will adapt principles proven in the US, frame them in terms of specific theoretical ideas which dovetail with principles drawn from our own previous (and highly complementary) research, and apply the resulting synthesis to design an intervention suitable for the UK.

Thus, our proposal relates centrally to RQ2 in the *Call for Outline Proposals*, in that we will be learning from the US experience of exemplary programmes which are *Standards*-based and research-informed. Our research also bears on all three remaining questions. In relation to RQ4, we will illustrate a type of innovation which offers great potential to improve engagement and learning –and hence longer-term participation– and to do this in a way that exemplifies a powerful approach to assessing effectiveness and feasibility of innovations. In relation to RQ3, our background pedagogical principles have already been found to be effective in the US in boosting participation and achievement, and our theory-guided refinements aim to enhance this further. Finally, our research will throw light on RQ1, in that we hypothesise that the features that make standards-based curricula exemplary are key shapers of participation, engagement and achievement.

Our work will focus on the early secondary years (Y7 & Y8 in England) during which students’ orientations towards science and mathematics as areas of study are established prior to choice of examination courses; at present, student attitudes to these subjects decline during this period (Galton et al., 2003; Steward & Pell, 2004). In addition, this phase is the earliest one in which reform becomes possible through working with relatively small cohorts of specialist secondary teachers rather than a very large cohort of generalist primary teachers. Finally, because this phase is relatively distant from the pressures of high-stakes external examinations, it offers better prospects of teachers, students and parents being willing to explore quite substantial change, providing a foundation for such change to subsequently work its way upwards through secondary education.

In the following sections, we shall provide further detail about our pedagogical principles, outline the curriculum contexts in which we shall be working, and explain our research and organisational approaches. We shall also show how we have responded to advice given on the outline proposal by: a) emphasising a range of student outcomes in examining the effectiveness of our intervention; b) considering students’ socio-economic status as well as gender and ethnicity; c) explaining how detailed observation and analysis add significant value; d) providing fuller information about the Project Advisory Board and its membership; e) elucidating the process for transferring results into practice (see also ‘communication plans and user engagement’).

Pedagogical principles and issues

The ‘exemplary’ US curricula to which we refer are organised around carefully-crafted problem situations, posed so

as to appeal to students' wider life-experience, to inculcate ideas of acting as mathematicians/scientists, and to develop key disciplinary ideas. Material is developed in lessons that cycle through whole-class introduction by teachers, collaborative problem solving in small groups, whole-class synthesis by teachers, and individual practice and consolidation by students. Our research will build upon these pedagogical principles, encouraged in part by their compatibility with teaching methods and curricular activities that we and other UK researchers in mathematics and science education have already successfully deployed (Howe et al., in press; Mercer et al., 2004; Mercer & Sams, 2006; Millar et al., 2006; Ruthven, 1989; Shayer & Adey, 2002).

We recognise that although *Standards*-based curricula have the potential to support effective pedagogical development (Remillard, 2005; Van Zoest & Bohl, 2002), they run the risk of being assimilated to established pedagogies (Henningsten & Stein, 1997), often by teachers replacing or revising materials to make lessons more skills-oriented and less open-ended, demonstrated to reduce their effectiveness (Schoen et al., 2003). Fundamentally, successful implementation depends on teachers believing that they and their students have the capacity to engage productively with this type of curriculum (Arbaugh et al., 2006). In particular, teachers and students cannot simply be expected to be able to participate effectively in the necessary forms of interaction: the development of their communicative skills and metacognitive awareness needs to become an explicit goal if it is to be successful, as also does the creation of a classroom environment in which there is clear, shared understanding of the value and functions of dialogue for learning (Alexander, 2004).

In addition to respecting principles that have emerged from research into standards-based curricula themselves, we also plan to refine the principles in the light of insights from social scientific theory in general. This theoretical framing of pedagogical principles will be central to the development process, notably in working with teacher co-researchers to design classroom methods and resources, and in developing techniques and instruments to analyse and evaluate the resulting intervention. Our attempts to appeal to students' interests and experiences will be informed by Donaldson (1978) and Freudenthal (1983), while also addressing the affective and epistemic complexities of knowledge growth (diSessa, 1993; Pintrich, 1993; Vergnaud, 1997). Activities will be designed to support reflexive, intentional learning (Bereiter & Scardamalia, 1989; Marton & Saljo, 1976), and recognise learning as a process of identity formation as much as cognitive organisation (Sfard & Prusak, 2005; Yackel & Cobb, 1996), helping learners to maximise agency in knowledge construction. Concern with collaborative activity, social interaction and classroom dialogue will be informed by the earlier work of team members (e.g. Howe et al., in press; Mercer, 1995), Cambridge colleagues (e.g. Alexander, 2004; Galton, 2004), and others (Lemke, 1990; Mortimer & Scott, 2003), which has analysed the crucial contribution that these processes make in bringing students to engage with differing perspectives so as to support effective learning.

Curricular topics and treatment

We plan to address three curricular topics. This is because the theorised principle of 'simplification by integration' (Iran-Nejad et al., 1990) suggests that an approach which co-ordinates and integrates mathematical and scientific treatments will provide students with additional capital to appreciate and benefit from the significance and interest of engaging problems. Furthermore, quantitative representation may facilitate conceptual growth in science (Carey & Spelke, 1994). We propose, therefore, to develop and evaluate a co-ordinated treatment of one 'subject spanning' topic module, alongside independent treatments of two 'subject-specific' topic modules.

Proportionality is the subject-spanning topic selected for co-ordinated treatment. The significance of the topic for mathematics is apparent from the current UK National Strategy (DfEE, 2001), where it is claimed that 'after calculation, the application of proportional reasoning is the most important aspect of elementary number' and it is during the early secondary years that 'secure foundations need to be established'. Significantly, proportionality is also identified as 'central in applications of mathematics in subjects such as science'. Although the National Strategy makes no explicit reference to proportionality in science (DfES, 2002), it requires coverage of many inherently proportional relations, e.g. size/weight in flotation, speed/stopping distance, temperature/dissolving, cell size/growth. Proportional reasoning is known to be challenging in both mathematical and science contexts (Boom et al., 2001; Karplus et al., 1983; Lesh et al., 1988; Piaget et al., 1977; Siegler, 1981), yet the *Standards*-based approaches on which we will build have proved to be effective in both contexts (Ben-Chaim et al., 1998; Huntley et al., 2000).

Within mathematics, we envisage a c.12-hour module that moves sequentially through: a) simplification, equivalence and comparison of percentages, fractions and decimals; b) calculation that includes decimals, fractions and percentages; c) relations between percentages, fractions, decimals and ratios; d) use of ratios in proportional reasoning – as detailed later, it will be at this final stage that links are made with science. The sequence does not correspond with the most relevant US scheme (Lappan et al., 2006), but research involving one member of our team (Howe et al., 2005a) indicates that it is essential. This is because UK students work on percentages, fractions and decimals during the preceding, primary school years, but not typically on ratios. Consistent with Lappan et al. (and the broad principles outlined above), each step will begin with engaging problems delivered through interactive whole-class teaching, e.g. use of ratios in proportional reasoning may begin with problems like '*Ming has a formula for mixing high-fibre and high-protein nuggets for baby chimps – 2 cups of high-fibre nuggets and 3 cups high-protein nuggets per chimp. What amount of high-fibre and high-protein nuggets will she need to feed 2 chimps? 3 chimps? 4 chimps?*' Students will then work in small groups on equivalent problems (see also discussion on

probability below). Plenary sessions will pull things together, and (reversing the typical approach) introduce such classic problems as *'Use ratios to compare the shaded and unshaded areas of this square'*. In other words, the function of the classic problems is to forge connections, not teach the mathematical procedures.

Although (as noted) proportional reasoning underpins many topics in secondary school science, we shall focus on one topic only for the science component, to facilitate the design of teaching materials and assessment instruments. The chosen topic is 'forces and their effects', comprising 6 sub-topics in the curriculum: a) Where do we come across forces; b) Why do things float? c) How do materials stretch? d) What is weight? e) What does friction do? f) What affects how quickly a car stops? Following the approach to be taken in mathematics, science teaching of the sub-topics will start with whole-class discussion of accessible scenarios, proceed to group work, and conclude with plenary sessions that facilitate abstraction. Group work will follow principles established by Howe et al. (2000) and Howe & Tolmie (2003), shown to be applicable in ordinary classrooms (Howe et al., in press) and demonstrably supportive of student identity formation as science practitioners. It will be structured around: a) discussion to establish consensual ideas (e.g. what determines whether objects will float or sink); b) practical exercises where groups map the relation between consensual factors and outcomes (e.g. how weight does/does not predict flotation – most groups will converge on the idea that light things float and heavy things sink); c) discussion in response to results with gradual realisation that weight relative to size more accurately predicts outcomes; d) instruction in how to compute density; e) further practical exercises where density (critically, size/weight ratios) is mapped against outcomes. Crucially, the fourth and fifth stages (d and e) will involve quantification, in effect the kind that students will be engaged in when using ratios in proportional reasoning during their (roughly) contemporaneous mathematics classes. To make the links even more explicit, problems will also be used during mathematics lessons that utilise science content, not just density/floating but also weight/stretching, speed/stopping distance, lubrication/stopping distance – all also covered in 'forces and their effects'.

Probability is the mathematical topic selected for independent treatment. A module lasting c. 6 hours will develop probabilistic reasoning through examining fairness and bias in the randomisation devices and games of chance that form part of most students' everyday interests and experience. Studies with the target age group have identified these as important referents in bridging between commonsense and schooled reasoning about chance (Amir & Williams, 1999; Greer, 2001; Pratt, 2001). Simple games will be presented with prepared dialogues, crafted to expose different modes of thinking, including prevalent but erroneous ones, such as an 'order blind' form of equiprobability bias (Lecoutre, 1992; Vidakovic, 1998), a 'decisive trial' form of determinist bias, and the 'negative frequency' form of representativeness bias (Kahneman et al., 1982) illustrated here: *'Pat: We'll each take a turn at tossing this coin. Let's play that I win if we both get the same face, otherwise you win; Sam: That's not fair, because you've got two ways of winning: 'heads & heads' and 'tails & tails'. Whereas I've only got one way: 'heads & tails'; Pat: Look, whatever happens on the first throw, the winner is decided by the second throw; Sam: Then I want to go second, so as to have the deciding throw; Pat: Fine, but it shouldn't make any difference. What matters for you is whether or not the second throw produces a different result from the first; Sam: So I'm actually more likely to win because heads and tails tend to even out.'* Equivalent dialogues will be incorporated in the mathematics teaching of proportionality, as already used by Howe et al. (2005a).

The prepared dialogues will be used to motivate small-group discussion of problem situations, and groups will be tasked to develop their own argument about fairness. Students will be encouraged to see the identification of assumptions and the development of arguments and counterarguments as central to mathematics as a 'thinking subject' and the learner of mathematics as a 'critical thinker'. Whole-class plenaries will focus initially on presenting, comparing and analysing arguments. Such analysis provides a platform for introducing relevant terms, concepts and techniques from the curriculum. Consolidation of these ideas will be through further individual and group work on problems designed to provide systematic variation of key elements. Whole-class review will promote development of transferable concepts and techniques and the eventual codification of central ideas and methods of theoretical probability.

The module will focus particularly on the 'reciprocal dynamic of theoretically computed probabilities and observed relative frequencies' which makes an important contribution to 'development of efficient probabilistic intuitions' (Fischbein & Gazit, 1984). One stimulus here might be the National Lottery claim that, 'Despite the draws being totally random, some numbers have a habit of cropping up more than others, while others hardly appear at all!' A key resource will be spreadsheet-based simulations of stochastic devices which permit the user to set parameters by dragging 'probability sliders', e.g. to introduce bias or ensure fairness. Research suggests that 'open box' simulations of this type make probability models more concrete and explicit to students (Pratt, 2001; Stohl & Tarr, 2002). A further lever to address student difficulties is to vary or combine representations of probability values, e.g. parameter values might initially be shown in terms interpretable either as percentage probabilities or odds ratios, with rational fractions introduced only at later stages. Such simulation tools can underpin diverse whole-class and small-group activity structures based on predict-check-explain tasks, and open to presentation in game format.

Electricity is the science topic selected for independent treatment, recognised as an area where students commonly experience difficulties (Chi, 1992; Millar, undated; Shipstone, 1985). Its importance has assured its place in recent curriculum revisions. Many applications of electricity are familiar to secondary students, providing obvious relevance for the topic, and offering real life contexts that may be readily linked to target conceptual knowledge (how can several circuits be independently switched from the same power supply (as in the home); how can

additional lamps be added to a circuit without substantial loss of brightness, etc.). Recent thinking has highlighted the role of models and analogies in learning (Buddle et al., 2002; Dupin & Johsua, 1989; Taber et al., 2006). Therefore research into the use of analogies, models, thought-experimentation and visualisation in learning science (Duit, 1991; Gilbert, 2004, 2005; Reiner & Gilbert, 2000) will inform the development of our teaching module on this topic. In other respects, the module will follow the structure outlined for the science component of our proportionality module.

In particular, students will work collaboratively on tasks designed to promote fertile dialogue, in order to test hypotheses and explore the value and limits of models. The tasks will offer opportunities for authentic reflection based upon models and analogies that have been found to be productive at this age (i.e. bread van 'circuits', and rope loops to support the differentiation of the core concepts of p.d., resistance and current). The cycling between teacher presentations, group problem-solving, and individual consolidation will provide the rhythm (Mortimer & Scott, 2003) to scaffold understandings of the abstract concepts and relationships core to scientific knowledge in the topic. Our approach will also meet recent concerns to strengthen teaching about the nature of science (Driver et al., 1996; McComas, 1998; Taber, in press), whilst supporting progression in learning thinking skills in science (Newberry et al., 2005). The QCA 'key concept' of scientific thinking ('using ideas and models to explain phenomena and developing them to generate and test theories' and 'critically analysing and evaluating evidence from observations and experiments'), will become a characterising feature for classroom scientific activity, offering a context for developing metacognition as well as supporting conceptual change (Gunstone & Mitchell, 1998).

The module will be developed using the electricity component of the IoP's Supporting Physics Teaching 11-14 (SPT) materials. The SPT materials have been designed, written, and reviewed by physics educators (including a member of our team - Taber), and incorporate many features that are consistent with our pedagogic model, e.g. an instructional approach informed by research into conceptual growth, the inclusion of student practical work to link to real-life situations (supplemented by simulations suitable for teacher presentation to ensure attention to the most pertinent issues). The SPT materials also link to 'key ideas' for energy and forces in the National Strategy (DFES, 2002), by presenting these as the basis for key 'explanatory stories' as recommended in 'Beyond 2000' (Millar & Osborne, 1998). The SPT materials also offer representations of the key physical relationships that allow teachers to visually demonstrate proportionality (e.g. $I \propto V$), thus linking to the subject-spanning topic.

Project organisation, research design and methods

Following a Phase α (Aug08/Sep08) for recruitment and preparation, the project will be organised in three main phases, associated with consecutive school years, leading to a Phase ω (Jul11/Jan12) for finalising conclusions and outcomes. Systematic methods of measuring and analysing aspects of knowledge growth and attitude change will be developed and piloted in Phase 1, trialled as a complete system in Phase 2, and fully implemented in Phase 3.

In Phase 1 (Oct08/Aug09) we will work with 20 teacher co-researchers (2 from science, 2 from mathematics, from each of 5 schools) to devise the classroom intervention, trial and refine components of the topic modules and evaluation instruments, and map patterns of classroom activity and trajectories of student learning. The 5 schools will be within daily travelling distance of the university, and operate in sufficiently varied circumstances to provide a sound basis for devising a widely transposable innovation. In Phase 2 (Sep09/Jun10) we will analyse –in terms of the guiding pedagogical principles– and evaluate –in terms of student engagement and learning– classroom implementation of the full modules by the teacher co-researchers. In each of these phases, video-recordings will be made of a sample of 30 lessons, to permit fine-grained analysis of how teachers activate the principles informing the materials and how students respond to them. Microanalysis of classroom dialogue and conceptual content will examine the structure of interaction and the ways in which it supports learning, the range of ideas introduced and the ways in which they are developed and interconnected over the course of lessons (Mercer, 2005). This detailed analysis is crucial to generate practical examples and guidance for teachers on classroom implementation.

During Phases 1 and 2, attention will also be given to developing construct validity and high reliability for all instruments and measures. A structured-response questionnaire will be developed to establish key student background characteristics (following the approach taken in the Trends in International Science and Mathematics (TIMSS) Study (Martin et al., 2004), and including socio-economic status, gender and ethnicity). A further questionnaire –designed to be administered at the start and end of school years– will assess aspects of attitude to science and mathematics, including facets of identity and forms of engagement (extending the TIMSS model of student attitude to take account of the wider aspects explicit in the pedagogical principles and their theoretical framing). Parallel forms of short domain-specific tests will be developed for each topic, in the light of National Strategy specifications for the topic and previous research into knowledge growth (as already referenced), to serve as pre-module, immediate post-module and deferred post-module assessments. Parallel forms of attainment test for start- and end-year assessment will be developed for mathematics and science as a whole by adapting the domain by demand model used in TIMSS. Last, a classroom observation schedule will be developed in the light of the pedagogical principles and lesson microanalysis, to record key features of classroom activity, interaction and discourse.

In Phase 3 (Jul10/Jun11) we will examine the repeated implementation of the modules by the 20 teacher co-researchers, alongside initial implementation by a large sample of further teachers. Schools for Phase 3 will be

chosen within a sampling frame recognising key features of variation in their circumstances, so that they collectively provide a sound basis for evaluating the innovation and assessing its transposability. We will recruit these new schools on the basis that half (15 schools; 2 teachers in each subject) will subsequently be randomly assigned (within the sampling frame) to implement the intervention, while the remaining half (15 schools; 2 teachers in each subject) will form a control group, continuing their established practice, guided by the appropriate National Strategy *Framework*. The 60 teachers in the intervention group will be trained at the start of Phase 3; after completion of Phase 3, the 60 teachers in the control group will receive training, revised in the light of evaluation. The 2-day training course will focus on the pedagogical principles operationalised in the topic modules, and on techniques of classroom practice aimed at supporting their implementation. Provision of materials supported only by modest training follows standard in-service models, and will thus establish whether the intervention is readily capable of scaling up.

Evaluation will be in terms of change in aspects of student attitude (as measured by structured questionnaire) and achievement (as measured by topic-specific and whole-subject tests), and will include scrutiny by socio-economic status, gender and ethnicity. Further analysis will examine how such changes relate to the classroom characteristics measured by the observation schedule. The basic forms of statistical analysis will be of repeated measures (start to end of school year, or pre-module to immediate-post-module to deferred-post-module), taking account of the hierarchical structure of the dataset. Where data are available from optional National Assessments these will be used to triangulate analyses. Account will be taken of standards for educational testing (AERA/APA, 1999), statistical methods (ASA/NSF, 2007) and curriculum evaluation (Confrey, 2006). There is potential also for a project extension to make a further and more controlled comparison, in those control-group schools which go on to implement the innovation following provision of training and materials, between student cohorts in the years before and after.

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Appendix 2: extract from ESRC Guidelines

Who can apply for a 3-Year ESRC Research Studentship (+3)?

2.13 Applications will only be considered from candidates who can demonstrate that they have already undertaken a programme of research training at postgraduate level in accordance with Sections D, E and F of the ESRC Postgraduate Training Guidelines (4th Edition 2005). Applicants should note that one of the main reasons that applications fail is because applicants are not able to fully justify and demonstrate appropriate prior research training. Thus, applicants are advised to pay particular attention to this to maximise their chance of obtaining a +3 award. Thus:

- If the applicant has already completed a Masters degree gained from a course which forms part of a currently recognised 1+3 programme, they are automatically eligible for +3 entry or
- If the applicant has a Master's degree which was gained in the UK from a course (including any previously recognised ESRC courses) which is not part of a current 1+3 programme or was gained overseas or has completed the first year of a PhD programme elsewhere, to be eligible they will need to demonstrate in the application form that this programme contained substantial training in research methods which would enable them to undertake an independent research project in a particular subject or interdisciplinary field. Furthermore, it must be demonstrated in detail on the application form that the programme of training already received was equivalent to both the generic and subject specific requirements set out in Sections D, E and F of the ESRC Postgraduate Training Guidelines.

2.14 Where a student is making a case for +3 entry it is essential to include:

- A FULL DESCRIPTION OF THE RESEARCH TRAINING UNDERTAKEN
- A DEMONSTRATION OF HOW THIS MAPS ONTO THE SPECIFIC GENERIC AND SUBJECT REQUIREMENTS OF THE GUIDELINES
- DETAILS OF FURTHER ADVANCED TRAINING TO BE UNDERTAKEN DURING THE PhD

It is important that the student completes this information on the application form in conjunction with the proposed supervisor. Please note that if the examiners judge that a case for +3 entry has not been made, the application will be withdrawn on eligibility grounds.

2.15 It should be noted that where a Master's degree was taken five years or more prior to the application for an ESRC research studentship, the training obtained in that degree will not be considered sufficient for a +3 award unless further relevant research training qualifications and/or experience and training has been gained subsequently. This must be fully detailed in the application.