ESRC End of Award Report

Grant Reference	RES-179-25-0003		
Grant Title	Effecting Principled Improvement in STEM Education (*epiSTEMe*): Student Engagement and Learning in Early Secondary School Physical Science and Mathematics		
Grant Start Date	01/11/2008	**Total Amount Expended:**	£ 613,130.08
Grant End Date	31/01/2013		
Grant holding Institution	University of Cambridge		
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1. **Non-technical summary**

Taking account of ideas and findings from previous research, the *epiSTEM*e project designed and trialled a teaching intervention intended to improve student attitudes to, and achievement in, early-secondary mathematics and science. The intervention employs a *dialogic* approach in which students and teacher discuss different points of view on thought-provoking problems, both in small groups and as a whole class. The problem tasks capitalise on research-based knowledge about how reasoning develops and about alternative conceptions that students commonly hold.

Adopting this type of teaching approach proved challenging for many teachers as it required them to break some habitual ways of thinking and acting in the classroom. To provide support, the intervention involves a two-day training programme. This introduces teachers to the approach, including lesson materials designed for use with their classes to cover science topics (Forces, Electricity) and mathematics topics (Fractions, Probability).

A randomised field trial of the intervention, involving 60 classes in 25 schools, produced encouraging findings. With three of the topics, *epiSTEM*e students made greater learning gains than students subject to normal teaching in control schools. With the final topic (Electricity), the difference between intervention and control groups was negligible. Within the intervention group, learning gain was positively associated with the level of dialogic teaching, particularly in mathematics. While the attitudes of *epiSTEM*e students to their experience of learning the target topics were generally positive, there was little difference from the control students.

Given that teachers were implementing a challenging intervention for the first time, these are promising findings.

2. Project overview

a) Objectives

The project's overarching aim was 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, in a form suited to wide-scale implementation. Subsidiary objectives were:

- to develop a system of pedagogical principles, explicitly grounded in an integrative framework of ideas from social scientific theory;
- to apply these principles to design a classroom intervention –suitable for wide-scale implementation– including illustrative topic modules on proportionality, probability and electricity;
- to develop, pilot and validate a system of instruments to assess the effectiveness of the intervention in enhancing student attitude and achievement;
- to pilot and refine the intervention and its supporting modules, analysing patterns of classroom activity and student learning associated with them;
- to analyse how characteristics of classroom dialogue and interaction relate to changes in student attitude and achievement;
- to design, pilot and refine a training programme introducing teachers to the pedagogical principles and the classroom intervention;
- to evaluate the intervention summatively, across a substantial and varied sample of schools;
- to review, in the light of all evaluations and analyses, the pedagogical principles and their underpinning social scientific theory.

b) Project Changes

No changes were made to the original aim and subsidiary objectives. Small modifications were made to some details of the project design as set out in the original proposal, and these have been notified in annual reports.

Because the number of schools and teachers recruited for the field trial was smaller than the maximum specified in the proposal, a corresponding proportion of the project budget for such participation has not been spent.

No changes were made to the team of investigators (as listed on the first page). Dr. Riikka Hofmann served as half-time research officer throughout the project, covered during her maternity leave from 03/2009 to 01/2010 by Ms. Fran Riga. Dr. Stefanie Luthman, the full-time research officer on the project, commenced maternity leave in 08/2011 with the intention of returning in 05/2012, possibly on a part-time basis, to undertake the main analysis of the field-trial dataset. A request to ESRC for project extension was made in 06/2011 and granted in 10/2011 on account of this maternity leave. However, following her husband's appointment to a postdoctoral fellowship overseas, Stefanie resigned her position in 01/2012. Dr. Paula Guardia was appointed to the vacant position from 04/2012.

c) Methodology

The project can be viewed as having three stages.

The first stage involved synthesising the most relevant pedagogical research, social scientific theory, and evidence about the current state of mathematics and science teaching in order to establish guiding principles. The main methods were narrative review of relevant literatures (Ruthven, Howe, Mercer, Taber, Luthman, Hofmann & Riga, 2010) and critical synthesis of recent systematic and meta-analytic reviews (Ruthven, 2011).

The second stage involved working collaboratively with a group of mathematics and science teachers to design, trial and refine the classroom intervention and suitable instrumentation for analysing and evaluating it. The main methods employed were design research (Ruthven & Hofmann, 2013), supported by pedagogically informed dialogue analysis (Ruthven, Hofmann & Mercer, 2011) and test, questionnaire and observation instrument design.

The third stage involved a randomised field trial of implementation of the intervention by teachers with a Year 7 mathematics or science class in schools new to the project. An open invitation to join the field trial was sent to schools across the Eastern region and into North London. All schools completing the application process were assigned to a treatment using an approach in which schools were paired according to school type and contextual value-added score, and then randomly allocated between the intervention or control group. One school withdrew prior to the start of the field trial because of staffing shortages. This yielded 25 participating schools: 12 in the intervention group, 13 in the control. Because many schools did not timetable their Year 7 classes until near the start of the school year, the assignment of school-nominated teachers to classes had to take place vicariously within each school without any involvement of the research team.

A 25-item attitude questionnaire (in parallel mathematics and science versions) was administered to the students in each participating class at the start and end of the school year. A series of pre-, immediate post- and deferred post-tests (tailored to the particular topic) were administered to all students when (and if) they studied one of the target topics over the course of the school year. The students also completed a 20-item opinion questionnaire (in parallel versions for each topic) after teaching of the target topic was complete. Finally, background data about students were gathered from school records and/or student questionnaires.

After attrition of 10 classes/teachers (i.e. insufficient data returns made), the number of classes/teachers included in the analysis was 60, comprising the following: in mathematics, 12 intervention, 16 control; in science, 16 intervention, 16 control. In the case of 5 intervention group teachers, data had also been collected in a second Year 7 class as a safety mechanism, but it did not prove necessary to fall back on these data for the analysis. The resulting data have been analysed using statistical methods that respect the hierarchical structure of the data set, with teacher/class taken as the higher level, and student as the lower level.

d) Project Findings

The main outputs and findings to date from the project are as follows:

1. The results of the first-stage synthesis of relevant literature to establish a system of pedagogical principles for the *epiSTEMe* intervention (Ruthven, Howe, Mercer, Taber, Luthman, Hofmann & Riga, 2010; Ruthven, 2011). This identified three teaching components of particular promise – referred to as domain-specific inquiry, cooperative groupwork, and contextual orientation – which could be brought together through a pedagogical approach in which dialogic teaching plays a central part.

2. The educative teaching materials and professional development activities which embody and illustrate the *epiSTEMe* pedagogical principles. The classroom intervention consists of an Introductory Module to support development of the dialogic teaching processes central to the *epiSTEMe* approach, as well as the two Topic Modules in each of mathematics and physical science.

3. Reliable, re-usable instruments for assessing student attitudes to mathematics and science, opinions on their classroom experience, and achievement in the target topics.

4. Research findings arising from the developmental activity to design and refine the intervention. The main findings to date relate to:

- principles and processes of design to operationalise the epiSTEMe pedagogical approach successfully (Ruthven, Hofmann, Howe, Luthman, Mercer & Taber, 2011; Ruthven & Hofmann, 2013);
- changes in classroom norms and teacher role necessary to implement dialogic teaching effectively (Ruthven, Hofmann & Mercer, 2011).

5. The core data set arising from the randomised field trial of the intervention. This includes a range of student background, attitude and achievement data from the participating classes.

6. Research findings from the randomised field trial. The main initial findings are as follows:

- In 3 of the 4 topics (Forces, Fractions and Probability), students subject to the *epiSTEMe* intervention made greater learning gains than those subject to schools' normal teaching (with a consistent effect size of around 0.25). In the final topic (Electricity), however, the difference between intervention and control groups was so small as to be statistically insignificant.
- Within the intervention group, the size of class learning gains was positively associated with the level of implementation of dialogic teaching, particularly strongly so in mathematics.
- There were few statistically significant differences between the attitudes of students in the intervention and control groups to their experience of learning the target topics, although attitudes were generally positive. The exceptions were that, in relation to Probability, students in the intervention group rated their experience higher in terms of seeing the value and application of the topic; and that, in relation to Electricity, students in the intervention group rated their experience higher in terms of being made to think hard, but lower in terms of generating interest in the topic.
- Broadly, there was no moderation of main effects by student background factors – gender, ethnicity, socio-economic status, English-language status.

Further analysis will take place to cross-check these initial findings and explore relations in greater depth.

7. The project website (http://www.educ.cam.ac.uk/research/projects/episteme/) provides information about the project with downloads of research papers and teaching materials and contact details for further information.

e) Contributions to wider ESRC initiatives (eg Research Programmes or Networks)

The project formed part of the ESRC Targeted Initiative on Science and Mathematics Education (TISME).

Members of the *epiSTEMe* project team participated in all the TISME day meetings and user events, hosting the meeting held in April 2010. Members of the project team also hosted a joint one-day meeting with the ICCAMS project team in November 2010, focusing on issues common to the two projects. 4 of the teacher participants in *epiSTEMe* attended the TISME/Royal Society seminar in February 2012 on Linking Teaching and Research and their contributions featured strongly in the resulting TISME publication.

K. Ruthven co-edited with M. Reiss a special issue of the *International Journal of Science and Mathematics Education* (9/2) on Enhancing the Participation, Engagement and Achievement of Young People in Science and Mathematics Education. The call for this SI and the editorial in the published SI drew attention to the Initiative, and the SI contained papers from the epiSTEMe, UPMAP and ASPIRES projects.

K. Ruthven served on the Advisory Group for the Initiative, and was one of the Initiative representatives at the Royal Society's two-day seminar on Research, policy and practice in science and mathematics education in February 2011.

3. Early and anticipated impacts

a) Summary of Impacts to date

The main potential for long-term impact on the scientific community to date is through the publications detailed on the ROS site at http://www.esrc.ac.uk/my-esrc/grants/RES-179-25-0003/read.

In September 2010, K. Ruthven was invited speaker on "The dialogic bases of effective inquiry-based science and mathematics education" at the launch conference of the EU Fibonacci project on *Raising awareness about Inquiry Based Science and Mathematics Education* (IBSME) *in Europe.*

Since 2011, C. Howe has been assisting Dr. Antonia Larrain with implementation of the e*piSTEM*e approach in Chile. Although only the Forces topic materials have been used, a similar number of schools have been involved and comparable results have been obtained. C. Howe visited Chile in 2013, giving a keynote address at a conference attended by over 200 policy-makers and practitioners and transmitted nationwide.

During 2012, N. Mercer was invited to give a keynote address on improving pedagogy to the annual conference for Coventry and Warwickshire headteachers, and to use e*piSTEM*e material to provide a series of workshops for teachers in Coventry schools on implementing a dialogic approach to teaching.

Recently, K. Taber made a presentation on the e*piSTEM*e science intervention to the professional development group of the national network of Science Learning Centres with a view to contributing some appropriate provision to their programme in future years.

Conference presentations have also been made, including BCME (2010; x2), BERA (2011; x 5), BSRLM (2011), EARLI (2011), ECER (2011), PME (2011), AERA (2012), and are forthcoming at EARLI (2013; x2) and the IoP Annual Teachers' Meeting (2013). Talks have also been given at King's College London (x 2) and the University of Nottingham (x 3).

The major way in which the project's research is currently being used outside academia is through the teachers from the mathematics and science departments of 30 secondary schools who have undertaken professional development on the e*piSTEM*e teaching approach and are making use of it and the supporting teaching materials. More British schools are now requesting permission to use the e*piSTEM*e materials in response to information on the project website.

The project held a dissemination event in January 2013 which attracted further interest in the e*piSTEM*e intervention from schools across the country and from intermediary organisations. Discussions have been initiated with key intermediary organisations which may be able to help disseminate the e*piSTEM*e approach and findings.

The project's research has been presented at a range of user events organised by the TISME programme.

b) Anticipated/Potential Future Impacts

We await with interest the outcome of the current National Curriculum review as the launch of the new curriculum presents a potential opportunity to promote the *epiSTEMe* intervention.

We continue to be responsive to schools and intermediary organisations seeking advice and support in developing a dialogic teaching approach to mathematics and/or science.

We have recently responded positively to a request from the Ministry of Education in the Cayman Islands, seeking to trial the *epiSTEMe* mathematics intervention.