The *epiSTEMe* pedagogical approach: essentials, rationales and challenges

Kenneth Ruthven, Riikka Hofmann, Christine Howe, Stefanie Luthman, Neil Mercer and Keith Taber
University of Cambridge

The goal of the *epiSTEMe* project is to develop a research-informed pedagogical intervention in early-secondary physical science and mathematics, suited to implementation at scale in the English educational system. This paper provides an overview of the pedagogical essentials of the *epiSTEMe* approach and their supporting rationales, and identifies some of the main practical challenges encountered.

Keywords: design research, dialogic teaching, early-secondary school, improvement at scale, linking mathematics and science, pedagogical design

Introduction

The goal of the *epiSTEMe* (Effecting Principled Improvement in STEM Education) project is to develop a research-informed pedagogical intervention in early-secondary physical science and mathematics, suited to implementation at scale in the English educational system (Ruthven et al. 2010). The project forms part of the ESRC's Targeted Initiative on Science and Mathematics Education [TISME] which is investigating ways of tackling participation and achievement gaps in these areas. This paper provides an overview of the pedagogical essentials of the *epiSTEMe* approach the supporting rationales, and some of the main practical challenges encountered.

We characterise our work as "re-design" research. This is to highlight that pedagogical improvement at scale needs to take account of the existing state of the system: notably the people, structures, resources and practices already in place. This work has been undertaken by a multidisciplinary university team working closely with a deliberately wide range of school practitioners. Against this background, the project has sought to use the accumulated body of national and international research on pedagogy to guide the design of a principled and effective approach to teaching and learning across the two foundational STEM subjects.

Systemic context and systematic research base

For over a decade, systemic improvement effort in England has taken place through the (now discontinued) National Strategies and (still continuing) processes of school inspection. These have promoted a pedagogy that combines tightly structured (inter)active teaching with target setting. Synthesis of national and international findings (Ruthven 2011) on English system performance suggests that this model:

- has raised content knowledge and skills in mathematics but not broader literacy or functional capability;
- has improved neither aspect of attainment in science;
- has raised student valuation of learning each of the subjects;
- has substantially lowered student liking of both subjects and enjoyment of learning them.

Thus the strongly instructional Strategies model has not been an unqualified success. Some degree of pedagogical adaptation is needed to address a full range of outcomes.

The international research base on effective pedagogy offers insights into forms of adaptation that might help. Although important gaps remain in this literature, synthesis of meta-analytic studies provides some clear indications of the relative effectiveness of certain teaching components, broadly validated through triangulation against other types of systematic review (Ruthven 2011). These particularly effective types of teaching component are as follows.

- *Domain-specific enquiry* (that poses authentic problems and takes student thinking seriously) is highly effective as regards attainment in both subjects and attitude in science (but is underinvestigated for mathematics).
- *Co-operative group-work* is relatively effective as regards attainment in both subjects and attitude in science but not in mathematics, as long as students have been properly prepared and activity is well structured.
- *Enhanced context* (in which teaching makes strong links to student experiences and interests) is particularly effective for science attainment (but is underinvestigated in relation to attitude, and for mathematics).
- *Active teaching* is relatively effective in developing content knowledge and skills in mathematics, although it is questionable as regards higher-order reasoning and functional thinking (but it is underinvestigated in relation to attitude, and for science).

It is this last teaching component which dominates the Strategy pedagogical model. Thus, placing greater emphasis on one or both of the first two components listed above represents the most plausible strategy for increasing the effectiveness of teaching in both subjects. The third component is promising but underinvestigated.

The *epiSTEMe* pedagogical model

The *epiSTEMe* pedagogical model blends the components found to be effective in the research synthesis outlined above into a pedagogical model that has been further informed by more specific bodies of US and UK research. This model has taken particular account of well researched US programs (cf. Reys et al. 2003; Riordan and Noyce 2001) that have been judged "exemplary" on the basis of evidence of effectiveness in multiple sites for multiple subpopulations (Department of Education, 1999). Guided by recent advances in theorising teaching and learning (e.g. as synthesised in Bransford, Brown and Cocking 2000; Duschl, Schweingruber and Shouse 2007; Kilpatrick, Swafford and Findell 2001), many of these programs employ a pedagogical model organised around carefully-crafted problem situations, posed so as to appeal to students' wider experience, to inculcate ideas of acting as mathematicians or scientists, and to develop key disciplinary ideas. Equally, the *epiSTEMe* model has been strongly influenced by UK research on classroom discourse and interaction (e.g. Mercer et al. 2004; 2006) which points to the value of dialogic small-group and whole-class discussion in encouraging students to talk in an exploratory way and to examine different points of view.

The basic pedagogical cycle at the core of the *epiSTEMe* model has three phases: exploration, codification, and consolidation (Ruthven 1989). In the opening exploratory phase, domain-specific enquiry tasks are employed to stimulate thinking by students that will support their development of target concepts. Dialogic small-group and whole-class discussion are used in this phase to encourage students to express their thinking about problem situations and to examine different perspectives on them. During such discussion, the teacher's principal role is to support the dialogic quality of contributions by students and exchanges between them. The cycle then proceeds to the ensuing codification phase in which the teacher's role becomes a more authoritative one of explaining accepted mathematico-scientific approaches to the problem situation. This involves (inter)active teaching which takes account of the thinking exposed and developed during the earlier exploration phase. In the consolidation phase, students tackle related problem situations more independently, with the teacher's role becoming one of checking student understanding and providing developmental feedback.

Some further pedagogical principles have guided the design of topic modules in each subject. In view of the favourable findings for 'enhanced context' in the research synthesis outlined above, attention has been given to conveying a sense of the wider human interest and social relevance of subject and topic (including, in mathematics, its scientific application), and to making relevant connections with widely shared student experiences and interests. The modules also take account of what is known about informal knowledge and thinking related to the topic; in particular, they provide means of deconstructing common misconceptions. Curricular prescriptions for the topic have been filled out to support the building of strong conceptual foundations. Finally, in the light of encouraging research evidence and emerging policy concerns, we have sought to develop the use of mathematical reasoning as a support for students' scientific understanding.

Scoping a (re)design strategy

A recent inspection survey (OfStEd 2008) has highlighted some major challenges to systemic improvement in lower-secondary mathematics (and likewise in science). The following have figured strongly in our experience:

- A narrow focus on accountability requirements in many schools;
- Internal and external pressure towards an objectives-driven pattern of teaching which focuses on immediate markers of superficial progress;
- Poor educational quality of many of the curricular resources available;
- Instability of staffing due to shortages of qualified subject teachers and the low priority that many schools accord to the early secondary phase;
- Many staff teaching areas where their subject-specific preparation is weak;
- Limited professional cohesion and developmental capacity in many subject departments.

Recognising these challenges, our goal has been to provide support for teachers and departments to work towards a renewed pedagogical approach without significant reorganisation and substantial investment of time. We have devised a professional development and classroom teaching intervention, of modest scope, packaged as a viable substitute for, or supplement to, modules currently widely taught in schools. We focus on Year 7, the first year of secondary education, as the point most distant from the inhibiting backwash of external assessment, and the period during which teachers are actively shaping new norms of classroom participation.

Originally we had hoped to develop greater coordination between the teaching of the mathematics and science modules, but it quickly became clear that persisting with this aim would deter many teachers and departments from participating. Equally, while we continue to recommend that at least two teachers from a department should collaborate in taking on the *epiSTEMe* intervention, with active support from senior leadership, so as to build a local community to support development of practice, we recognise that this can prove difficult to achieve in some departments and schools.

The *epiSTEMe* apparatus, then, consists of the following components. An Introductory Module has been designed to build teacher and student understanding of the value of talk and dialogue in supporting subject thinking and learning, and to develop rules and processes that support effective small-group and whole-class discussion. Two Topic Modules (in each subject) have been designed to support and capitalise on such use of talk and dialogue, and to instantiate key pedagogical principles and processes. (In mathematics, these modules are on fractions, ratio and proportion, and on probability; in science, on forces and proportional reasoning, and on electricity). All the modules are mediated by teaching materials designed to be educative in the sense of supporting teacher development as well as classroom activity (Davis and Krajcik 2005), supported (on a realistically modest scale) by a sequence of two one-day professional development events. The first event focuses on dialogic teaching and on how the Introductory Module supports its development; after teachers have undertaken the Introductory Module with one of their classes, the second event debriefs this experience and examines how the Topic Modules in their subject incorporate the pedagogical principles and processes of the *epiSTEMe* model.

In designing modules, we made many decisions intended to ensure that a wide range of teachers and departments would find them readily and robustly usable in their particular situation. The Introductory Module features relatively short activities that can be used flexibly over a number of lessons. The Topic Modules provide a full set of classroom materials which explicitly target curricular objectives. The sequence of activities within Topic Modules is straightforwardly adjustable to lesson length and pace, and the duration of each module is that typically allotted to the topic. Equipment requirements are limited to resources known to be widely available and easily usable. The Teaching Notes support lesson planning, highlight key aspects of activities and explain the underlying rationale for them, and advise on handling a range of student responses. Finally, in the light of particular difficulties that we found many teachers encountering, the classroom materials provide scaffolding to support dialogic processes, particularly the articulation by students of their reasoning.

An illustrative teaching activity

To illustrate the epiSTEMe approach more concretely and describe some of the challenges that teachers encountered in realising it, we will use the example of an activity that focuses on a simple probabilistic model of genetic inheritance. The key genetic ideas underpinning the model (as shown on the first slide in Figure 1) are introduced through interactive whole-class teaching. Students are often surprised to learn of the two earlobe types; typically they show great interest in knowing which type they and their classmates have! The probabilistic aspect of the model (as shown on the second slide in Figure 1) is then introduced and examined through two simple examples. As early as this point it is not unusual for some student to pose the question of whether attached earlobes will eventually die out; this is acknowledged by the teacher to be an interesting question that it may be possible to address in due course. Typically, some student asks whether both problems on the second slide concern the same child or what would happen if they did; this provides a good lead into the problem that students are then asked to work on, initially in small groups: *A couple are expecting their first baby. Both parents have a mixed pairing of e and E alleles. How likely is their baby to have this same pairing?*

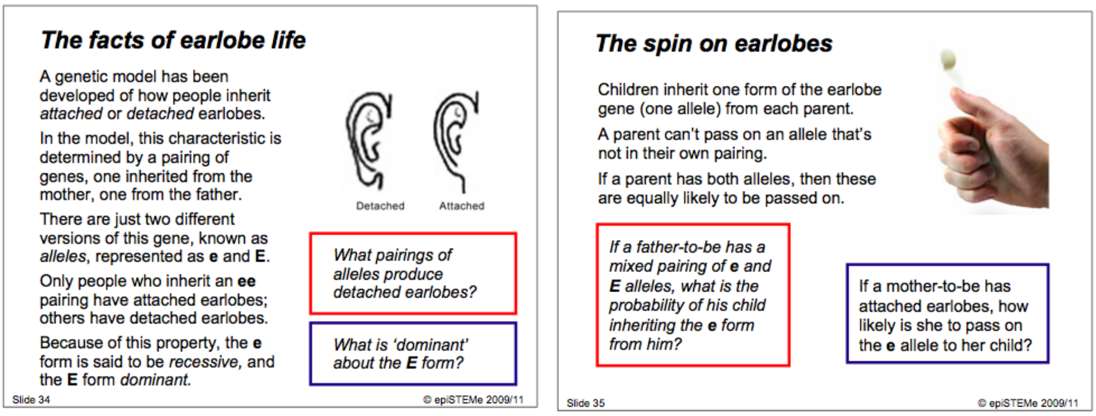

Figure 1: The two slides used to introduce the simple probabilistic model of genetic inheritance.

An important ground-rule for small-group discussion is that students should try to come to an agreed position; even if they are unable to achieve this goal, honouring it helps to ensure that they engage with points of view other than their own, and that they seek to develop an argument in support of their position. Once most groups have formulated some kind of collective response, the activity switches to whole-class plenary discussion of the range of answers and arguments that the groups have arrived at. This problem is a good one for generating dialogic discussion between students during the plenary. Typically, initial small-group work on the problem creates a situation in which there is a clear need for further whole-class discussion, because it has elicited what are clearly contrasting answers from different groups. Moreover, each answer arises from a distinctive pattern of reasoning: an everyday model of inheritance in which "children take after their parents" (leading to a 100% answer) as well as variant patterns of probabilistic reasoning about the outcome space under the scientific model of genetically-mediated inheritance (leading to answers of 1/3 and 50%). These three responses represent, respectively, the predominant everyday misconception about inheritance of characteristics, the predominant lay misconception about outcomes in a simple repeated trial, and finally the fully coordinated conceptualisation in accepted mathematico-scientific terms.

In the first *epiSTEMe* professional development event, we employ the example of a plenary session on this problem to examine the role of the teacher in supporting and developing dialogic exchange. As a stimulus for discussion with and between teachers, we use a sequence of short video episodes (with the associated dialogue transcribed to encourage attention to the fine grain of students' mathematical thinking and the teacher's participation in the discussion). The focus is on "reading" what is taking place as each episode unfolds so as to understand how students are thinking and responding, to analyse the quality of dialogic interaction, and to anticipate accordingly how the teacher might productively shape events and ideas.

Supporting this type of dialogic discussion is the aspect of the *epiSTEMe* pedagogical model that teachers have found particularly challenging. Because the *epiSTEMe* approach emphasises developing thinking as its goal, not simply securing performance, it requires many teachers to make significant shifts beyond the received ideas and habitual reflexes of established practice. For example, a dialogic approach calls for the teacher to be prepared to give time not just to multiple and sometimes extended student contributions, but to contributions that are persuasively fallacious or poorly formulated. Moreover, teachers need to draw on a nuanced understanding of the topic which enables them to support development of student conceptualisation and reasoning. To sustain productive discussion, the teacher must be able to identify and interanimate the thinking behind different student responses, and steer progression in reasoning without closing down discussion through overly authoritative intervention. Our research analysis of this videotaped plenary sequence (Ruthven, Hofmann and Mercer 2011) has enabled us to help teachers make such a transition by concretising the varied ways in which they can support the dialogic quality of class discussion.

References

Bransford, J., A. Brown, and R. Cocking, eds. 2000. *How People Learn: Brain, Mind, Experience, and School.* Washington DC: National Academies Press.

Davis, E. A., and J. S. Krajcik 2005. Designing educative curriculum materials to promote teacher learning. *Educational Researcher* 34 (3): 3-14.

Department of Education 1999. *Exemplary and promising mathematics programs.* Washington DC: Department of Education.

Duschl, R., H. Schweingruber, and A. Shouse, eds. 2007. *Taking Science to School: Learning and Teaching Science in Grades K-8.* Washington DC: National Academies Press.

Kilpatrick, J., J. Swafford, and B. Findell, eds. 2001. *Adding it up: Helping children learn mathematics.* Washington DC: National Academy Press.

Mercer, N., L. Dawes, R. Wegerif, and C. Sams 2004. Reasoning as a scientist: ways of helping children to use language to learn science. *British Educational Research Journal* 30 (3): 367-85.

Mercer, N., and C. Sams 2006. Teaching children how to use language to solve maths problems. *Language & Education* 20 (6): 507-27.

Office for Standards in Education [OfStEd] 2008. *Mathematics: Understanding the score.* London: OfStEd.

Reys, R., B. Reys, R. Lapan, G. Holliday, and D. Wasman 2003. Assessing the impact of Standards-based middle grades mathematics curriculum materials on student achievement. *Journal for Research in Mathematics Education* 34 (1): 74-95.

Riordan, J., and P. Noyce 2001. The impact of two Standards-based mathematics curricula on student achievement in Massachusetts. *Journal for Research in Mathematics Education* 32 (4): 368-98.

Ruthven, K. 1989. An exploratory approach to advanced mathematics. *Educational Studies in Mathematics* 20 (4): 449-67.

——— 2011. Research-informed pedagogical innovation at scale in school mathematics and science education. Paper presented at the British Educational Research Association. London, 6-8 September 2011. Accessed 12 Dec 2012 at http://www.educ.cam.ac.uk/people/staff/ruthven/RuthvenBERA11paper.pdf

Ruthven, K., R. Hofmann, and N. Mercer 2011. A dialogic approach to plenary problem synthesis. *Proceedings of the 35th Conference of the International Group for the Psychology of Mathematics Education*, Vol. 4: 81-8.

Ruthven, K., C. Howe, N. Mercer, K. Taber, S. Luthman, R. Hofmann, and F. Riga 2010. Effecting Principled Improvement in STEM Education: Research-based pedagogical development for student engagement and learning in early secondary-school physical science and mathematics. *Proceedings of the British Society for Research into Learning Mathematics* 30 (1): 191-8.