Developing a principled and effective pedagogy

The *epiSTEMe* experience of redesigning classroom teaching and learning in lower-secondary-school mathematics and science

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This paper will examine some major considerations of pedagogy bearing on the design research being undertaken by the *epiSTEMe* project to redesign classroom teaching and learning in lower-secondary-school mathematics and science.
The epiSTEMe project

- Part of the ESRC’s targeted research initiative on Science and Mathematics Education
  - Investigating ways of addressing participation and achievement gaps in science and maths education
- A (re)design research project
  - Undertaken by a multidisciplinary university team working closely with school practitioners
  - Focusing on student engagement and learning in early secondary-school physical science and mathematics
  - Researching, developing and evaluating a pedagogical intervention suited to implementation at scale

The epiSTEMe project forms part of the ESRC’s Targeted Research Initiative on Science and Mathematics Education [TISME] which is investigating ways of tackling participation and achievement gaps in these areas. The project is seeking to understand and address issues of student engagement and learning in physical science and mathematics, with a specific focus on the crucial lower-secondary-school phase. The research is being undertaken by a multidisciplinary university team working closely with school practitioners.

The goal of the project is to develop a research-informed pedagogical intervention, suited to implementation at scale in the English educational system, and intended to illuminate how the quality of student engagement and learning in early-secondary mathematics and science could be improved.

Our adoption of a “redesign” stance recognises that pedagogical improvement at scale must take account of the existing state of the system and the resources and practices already in place. This constrains design possibilities: redesign must take place within those degrees of freedom that current circumstances afford. Within this envelope, the project has sought to use the cumulative body of national and international research on effective pedagogy to guide the design of a principled and effective approach to teaching and learning.
Principled and effective pedagogy: the systemic context in England

- For more than a decade, systemic improvement effort has taken place through the National Strategies.
- This has promoted a pedagogy that combines tightly structured interactive teaching with target setting.
- National and international findings are that this model:
  - has raised content knowledge and skills in mathematics but not broader literacy or functional capability;
  - has not improved either 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.
Equally, analysis of the systematic research base available can be summarised as follows.

Important gaps remain in the evidence base.

Nevertheless, there are some clear findings from meta-analytic syntheses, that are broadly validated through triangulation against other types of systematic review.

The main findings on effective pedagogical components are that:

- **Domain-specific enquiry** (that poses authentic problems and takes student thinking seriously) strengthens attainment (in both subjects) and attitude (at least in science).
- **Co-operative groupwork** strengthens attainment (in both subjects) and attitude (at least in science), as long as students are properly prepared and activity well structured.
- **Enhanced context**, linked to student experiences and interests, is beneficial (at least for science attainment).
- **Active teaching** is effective in developing content knowledge and skills in mathematics but questionable as regards higher-order reasoning and functional thinking.
Core epiSTEMe pedagogical model

- Blends the pedagogical components found effective through systematic research synthesis
- Cycles through phases in which the key ideas of the topic are explored, then codified, then consolidated
- Employs domain-specific enquiry tasks to stimulate thinking that will support development of key ideas
- Makes use of dialogic small-group and whole-class discussion, mainly in the exploration phase
- Makes use of active teaching, particularly in the codification and consolidation phases
- Provides individual checks on understanding with developmental feedback during consolidation phase

The core pedagogical model developed for the epiSTEMe intervention blends the pedagogical components that systematic research synthesis has found to be effective.

Each module focuses on a particular mathematical or scientific topic and cycles through phases in which key ideas are explored, then codified, then consolidated.

Domain-specific enquiry tasks are employed to stimulate thinking that will support development of key ideas. Dialogic small-group and whole-class discussion are used, mainly in the exploration phase, to encourage students to talk in an exploratory way and to examine different points of view. Here the teacher’s role is to support the dialogic quality of discussion. In the codification and consolidation phases, the teacher’s role becomes a more directly instructional one, involving greater use of active teaching. In the consolidation phase, there is an emphasis on individual checks on student understanding with developmental feedback.
Further *epiSTEMe* pedagogical principles in design brief for topic modules

- To fill out curricular prescriptions for the topic to build strong conceptual foundations
- To show the human interest and social relevance of the topic (including, in maths, scientific application)
- To make connections with widely shared student experiences and interests relevant to the topic
- To take account of students’ informal knowledge and thinking related to the topic
- To provide means of deconstructing common misconceptions related to the topic
- To develop mathematical reasoning as a support for students’ scientific understanding

Beyond this core pedagogical model, further pedagogical principles guided the design of *epiSTEMe* topic modules.

Curricular prescriptions for the topic, often atomised into isolated objectives, were filled out to support the building of strong conceptual foundations.

Appropriate attention was given to conveying some sense of the wider human interest and social relevance of the topic (including, in maths, scientific application), as well as to making connections with widely shared student experiences and interests relevant to it.

This helped the modules, in turn, to take account of students’ informal knowledge and thinking related to the topic; at the same time, pedagogical tasks and processes were designed to provide means of deconstructing common misconceptions related to the topic.

Finally, in the light of encouraging research evidence and emerging policy concerns, we sought to develop mathematical reasoning as a support for students’ scientific understanding.
Challenges to systemic improvement in lower-secondary maths and science

- Narrow focus on immediate accountability requirements in many schools
- Diversity of local curricular patterns and organisational practices, often strongly embedded
- Instability and marginality of staffing due to teacher shortages and low priority of early secondary
- Appreciable proportions of staff teaching areas for which their subject-specific preparation is weak
- Lack of professional cohesion and developmental capacity in many subject departments
- Limitations of cascade methods as against costs of teacher participation in deeper developmental activity

Some major challenges to systemic improvement in lower-secondary mathematics and science had been highlighted in recent inspection surveys. The following have figured strongly in our experience:

- A narrow focus on immediate accountability requirements in many schools;
- Considerable diversity in local curricular patterns and organisational practices, which are often strongly embedded, but rarely deeply considered;
- Instability and marginality of staffing due to teacher shortages and the low priority accorded to the early secondary phase;
- Appreciable proportions of staff teaching areas for which their subject-specific preparation is weak;
- Lack of professional cohesion and developmental capacity in many subject departments;
- Limitations of cascade methods as against costs of teacher participation in deeper developmental activity.

Recognising these challenges, we decided to devise an intervention of modest scope, packaged as a viable substitute for existing topic modules. We chose to focus on Year 7, the first year of secondary education, not only because this is when teachers are actively shaping new norms of classroom participation, but also because it is most distant from the backwash of external assessment. Originally we had hoped to develop greater coordination between mathematics and science teaching, but it quickly became clear that persisting with this aim would deter many teachers and departments from participating.
The intention, then, was to provide a means by which departments and teachers could explore a new pedagogical model without heavy reorganisation, commitment or investment. Our approach was to develop treatments of two topics in each subject area along lines illustrative of the *epiSTEMe* pedagogical approach, mediated by teaching materials designed to be educative (in the sense of supporting teacher development as well as classroom activity), and supported by associated professional development (on a realistically modest scale). The *epiSTEMe* apparatus, then, consisted of:

**The *epiSTEMe* apparatus**

- An Introductory Module intended:
  - To build teacher and student understanding of the value of talk in supporting subject thinking and learning
  - To develop rules and processes that support effective small-group and whole-class discussion

- Two Topic Modules (in each subject) intended:
  - To support and capitalise on use of talk and dialogue
  - To instantiate key pedagogical principles and processes

- Two professional development days intended:
  - To develop understanding of dialogic teaching and of how the Introductory Module supports its development
  - To debrief experience of teaching the Introductory Module and develop understanding of the pedagogical principles and processes underpinning Topic Modules

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- To debrief experience of teaching the Introductory Module and develop understanding of the pedagogical principles and processes underpinning Topic Modules.
Design features for improvement at scale in face of typical challenges

- Introductory Module features relatively short activities that can be used flexibly over a number of lessons
- Topic Modules provide full set of classroom materials which explicitly target curricular objectives
- Sequence of activities within Topic Modules is readily adjustable to lesson length and pace, and occupies typical time period currently allocated to topics
- Equipment requirements are limited to resources known to be widely available and easily usable
- Teaching Notes support lesson planning, explain underlying rationale and key aspects of activities, and advise on handling a range of student responses
- Classroom materials provide scaffolding to support dialogic processes, particularly articulation of reasoning

In devising modules, we made many decisions intended to ensure that a wide range of teachers and departments would perceive them as being readily, flexibly and robustly usable in their particular situation.

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The Teaching Notes support lesson planning, explain the underlying rationale for, and key aspects of, activities, and advise on handling a range of student responses.

Finally, in the light of particular difficulties that many teachers encountered, the classroom materials provide scaffolding to support dialogic processes, particularly the articulation of reasoning.
To illustrate the epiSTEMe approach more concretely and describe some of the challenges that teachers encountered in realising it, we will use an example that we have found productive in our professional development efforts. The context is a lesson on the probabilistic thinking underpinning a very simple genetic model of inheritance. This is introduced to students through providing both basic information and more probing questions aimed at helping them engage with it. The students are then asked to tackle the more demanding problem shown.

One session in our professional development examines how the teacher might manage and participate in the plenary discussion following up small-group work on this problem. As a stimulus for discussion between teachers, we use a sequence of short episodes from a video (with talk transcribed) where one pilot teacher is handling such an episode. The focus is on “reading” what is taking place with a particular view to understanding how students are thinking and responding and to anticipating how the teacher might productively shape the evolving whole-class discussion.
The problem is a good one for generating dialogic discussion between students. 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 elicits a range of answers from different groups (as shown by the list written on the board), each of which is associated with a distinctive pattern of reasoning. This includes patterns of reasoning influenced by an everyday model of inheritance (leading to the 100% response) as well as by variant patterns of probabilistic reasoning about the scientific model (leading to the 1/3 and 50% responses).
Teacher participation in dialogic whole-class discussion

T: Kitty.
S[Kitty]: There's three different outcomes but there's two ways of getting one outcome so that outcome has a higher probability than the other two.
T: Okay. So Hanna, does that make, does that make any difference do you think? Kitty’s saying that although there are only three outcomes [pause]
T: All those people who are getting restless think of something that you can tell us that will convince people of what’s going on, convince them of what you believe, because the majority of you are saying that there’s a fifty per cent chance they will have the same grouping as their parents. We have some people who don’t agree, and they have good reasons for not agreeing....

Teacher solicits contribution from student who has shown shift to sound idea
Teacher accepts this contribution without explicit evaluation
Teacher invites revised contribution from student who expressed confusion
Teacher revoices contribution from student expressing sound idea
Teacher asserts norm of being open to other views, and making constructive contributions aimed at persuasion

Our research analysis of this sequence has highlighted a range of ways in which the teacher participates to support the dialogic quality of whole-class discussion. The particular episode shown here occurs towards the end of the discussion where the teacher is scaffolding public dialogue between the contrasting probabilistic points of view proposed by two students, while reminding some other students of the expected norms of engagement in this kind of discussion even when they believe that they know the correct answer.
Facets of teacher participation in dialogic whole-class discussion

- **Supporting interanimation of ideas**
  - Teacher allows extended student contributions, including those advancing fallacious reasoning
  - Teacher revoices student contributions to summarise them, make them more clearly relevant, and establish connection to earlier contributions

- **Hedging epistemic authority**
  - Teacher makes contributions that are predominantly organisational and/or reflexive
  - Teacher accepts student contributions without evaluating them, and declines student invitations to do so, asserting norm of class agreement
  - Teacher scaffolds through prompts and initiations but fades to allow development by students

Over the course of this sequence of 10 minutes or so, the teacher displays an extensive repertoire of forms of participation which we have organised under five overarching themes. This slide and the next one show these themes and some of the forms of participation associated with them.

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Facets of teacher participation in
dialogic whole-class discussion (cont.)

- **Maintaining dialogic norms**
  - Teacher asserts norm of being open to other views, and making contributions aimed at persuasion
  - Teacher affirms norm of being open about holding views that diverge from emerging class consensus

- **Managing progression in reasoning**
  - Teacher solicits contributions from students who have shown understanding [without making this explicit]
  - Teacher invites revised contributions from students who have shown misunderstanding [again implicitly]

- **Prompting shifts in reasoning**
  - Teacher reacts by soliciting specific clarification
  - Teacher prompts attention to mathematical principle, use of mathematical tool, or link to earlier problem

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Teacher prompts attention to a mathematical principle, or comparison with a previous problem, or use of a mathematical tool
Supporting dialogic discussion, in the (rather different) small-group and whole-class contexts 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 significant shifts beyond the received ideas and reflexes of established practice:

- Aiming to express reasoning not just produce answers;
- Giving time to multiple extended student contributions;
- Allowing extended student contributions that are fallacious;
- Interanimating the reasoning behind student responses;
- Making contributions that are reflexive not regulative;
- Steering discussion to secure progression in reasoning but not closing it down through authoritative intervention.

Challenges for teachers in embracing and realising dialogic pedagogy

- Realising the dialogic element of the epiSTEMe pedagogy has proved challenging for many teachers.
- The goal of developing thinking, not simply securing performance, requires significant shifts beyond the received ideas and reflexes of established practice:
  - Aiming to express reasoning not just produce answers;
  - Giving time to multiple extended student contributions;
  - Allowing extended student contributions that are fallacious;
  - Interanimating the reasoning behind student responses;
  - Making contributions that are reflexive not regulative;
  - Steering discussion to secure progression in reasoning but not closing it down through authoritative intervention.