Promoting Inquiry in Science Classrooms in European Schools (PISCES)

A Handbook for Tutors

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Preface

In Scotland, PISCES stands for ***Promoting Inquiry Skills for a Curriculum for Excellence in Science***. It is a CPD module for teachers of science, which has been developed in Scotland with the support of the S-TEAM project. However, this Handbook uses our international acronym in which PISCES stands for **Promoting Investigative Skills for Collaborative E(I)nquiry in Science.**

It has, we believe, the potential to be as successful across Europe as it has been in Scotland, as it was designed around the idea of empowering teachers to think for themselves and make their practice more inquiry based, wherever they are. It is, however, recognised that some educational environments may be more supportive of 'inquiry-based practice' than others.

PISCES empowers teachers to make large or small changes to their practice, according to their situation, their aims and the perceived needs of their pupils. We have been careful to use the word 'more' in 'more inquiry-based', as teachers almost always use some elements of inquiry in their practice. There is, furthermore, no single model of inquiry being 'pushed' here. Indeed, it is a measure of the success of PISCES that the participating teachers did very different things in making their practice more inquiry-based.

PISCES itself has evolved in the context of the EU perception that more inquiry-based science education is the way forward, in order to increase scientific literacy and to address problems of recruiting young people to careers in science, technology and mathematics. S-TEAM (***Science-Teacher Education Advanced Methods***) is a European Union Framework Programme 7 project involving 26 teacher education institutions across 15 countries. It runs from 2009-2012, and aims to help teachers overcome obstacles to inquiry-based learning.

Strathclyde University is a leading partner in S-TEAM. Members of Strathclyde University, along with the Development Officer for Curriculum for Excellence for East Lothian, successfully developed and delivered a pilot version of PISCES as a module to a group of East Lothian teachers, in 2010/11. The module resulted in successful 'experiments in practice' and increased awareness of the benefits of inquiry-based teaching and learning. The same group of teachers have also taken part in a follow-up course (ARIES: Advanced Resources for Inquiry and Evaluation in Science).

PISCES is a high quality CPD programme, valued by teachers and supportive of their professional self-development. It can be applied to both primary and secondary teaching, in all science subjects. Pupils benefit from learning experiences, which develop scientific inquiry skills. Feedback from participating teachers has been consistently positive, for example:

"The course has been enjoyable but challenging so far, and has really made me think about my practice"

"I am starting to think about my lessons and how to approach them with inquiry principles, very enterprising. The pupils are surprising me"

"I think we need to cut down on the [curriculum] course content so we can do much more of this level of [inquiry-based] teaching"

From the teachers' perspective

Teachers valued:

- The chance to take part in a University sponsored module.
- A module structure that supported reflection upon their own practice, and enabled them to plan, implement and evaluate their own interventions.
- Conceptual models, which helped them to reflect on the nature of investigations and to develop scientific thinking in themselves and their pupils.
- The support and encouragement given during the module, both by module leaders and the group.

From the S-TEAM/ Strathclyde University perspective

We were impressed by the fact that PISCES:

Empowered teachers to reflect on their practice, and innovate in the classroom.
Led to a range of exciting interventions in classes for pupils aged 5 to 17, all involving inquiry in some form, developed by the teachers according to their own contexts and concerns for their pupils.
Consistently led to teachers developing practices that engaged their pupils and empowered them to take more ownership of the topics being explored.
Led to interventions that demonstrated enhanced pupil thinking and learning.

Involvement and accreditation by Strathclyde University validated the module and enabled it to be challenging in its expectations.

This guide aims to help those considering running PISCES (and in adapting as necessary to one's own context) as tutors. It presents PISCES as it was run in East Lothian, pointing out those parts where we think tutors may wish to adapt it.

Prospective tutors should be aware, however, that, PISCES is experimental and exploratory. Also, as will become clear on reading the handbook, although we believe the module will always be empowering, the actual outcomes will be different with different groups of teachers. That is another exciting aspect of it, however. New findings, interesting to research, are likely to emerge each time.

Author information.

Colin Smith is a former Biology Teacher with over 30 years experience who is currently working as a Research Associate on Work Package 5 of the S-TEAM Project led by Professor Jim McNally. During his time as a teacher, he was seconded twice to research projects. The first with Edinburgh University aimed to find ways to bridge the research-practice divide in ways that enabled teachers to use research-based findings and theories in their practice. On completion of this project, he continued to lead a Professional Development Group in his school. The second secondment was as a teacher-researcher with the ESRC/TLRP-funded Early Professional Learning (EPL) project, collecting data and disseminating to schools and local authorities on the implications of the findings for them. He has led the development of PISCES in its aim of working with teachers in solving problems in making teaching more investigative within the realities and constraints that impinge upon them. He has published and presented papers based on these projects.
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Allan Blake
Allan Blake was a research fellow on the ESRC/TLRP-funded Early Professional Learning project, a multi-method study designed to improve the learning experience of new teachers by developing a research-based, practical model of early professional development. The project used ethnographic data as a basis for model building and testing in a correlational design, involving five quantitative indicators of new teacher development and a qualitative data set of interviews with 154 new teachers in 45 schools in Scotland and England (McNally & Blake, 2010)). At the University of Strathclyde in Glasgow, Allan is a research fellow on S-TEAM project, and, also, in partnership with the University of Oxford, the ESCalate funded Work of Teacher Education project. He is interested in the enhancement of research and critique in teacher education through a wider literary reference base.
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Peter Gray, although resident in Scotland, works for the Norwegian University of Science and Technology (NTNU) in Trondheim. One of his tasks is Project Manager of S-TEAM, a role in which he coordinates the work, and its dissemination, of 26 institutions across 15 countries. He studied adult education and film and has worked on a variety of EU and nationally-funded research projects, including being researcher

on the EPL project at the University of Stirling. His research interests are spatiality, education reform and European Union education policy in STEM subjects. His unique background has enabled him to bring an international perspective to the development of PISCES.
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Jim McNally is Professor in Teacher education at Strathclyde University. Jim was a former physics teacher and Assistant Head Teacher in Scottish secondary schools. Previously to S-Team, he led the ESRC/TLRP-funded Early Professional Learning project, inquiring into the learning of new teachers (McNally and Blake, 2010). This project, in line with his philosophy of co-operation between practitioners and academic researchers, was innovative in the way that teachers worked in partnership with academics as the main researchers involved in gathering the data, contributing also to its interpretation and dissemination to the educational community.

Jim's research interests and publications are in three main areas:

- Teacher Development - the student teaching experience, mentoring beginning teachers, management of induction and its relationship to continuing professional development
- Teaching Investigative Science: how teachers make sense of their practice, conditions which enable beginning teachers to learn how to teach by more inquiry-based methods.
- Building Grounded Theory: as in the above fields and generally from teachers' thoughts about their practice.

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Sinclair Mackenzie teaches Physics at Thurso High School and is a member of the Reference Group for S-TEAM. He left an engineering career in semiconductors and biophotonics to train as a science teacher in 2006. Sinclair has maintained a personal blog since 2000 and started his Fizzics blog during a PGCE school placement when he recognised their potential in learning and teaching. He has recently presented on his use of the blogging and podcasting in the classroom at the Association for Science Education's Scottish conference and the Highland Learning Festival. Sinclair has contributed a chapter giving a teacher's perspective on achieving multiples literacies in the science classroom in "Multiple Literacy and Science Education" published by IGI Global.
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Contents

Chapter 1: Introduction and rationale

(See also, Appendix 1)

The idea behind this Handbook is to present PISCES to people who would consider acting as tutors. We focus on how it worked for us in delivering it to the teachers from East Lothian. The materials we used will be presented in appendices, matched to the chapters discussing each session – for example, Appendix 1 contains the Module Outline that was provided, along with the pre-module activity (Chapter 2 and Appendix 2) to the participating teachers a couple of weeks before the module began. The hope is that, in both seeing how it worked and the actual materials used, prospective tutors can see how to adapt PISCES to their own contexts and personal backgrounds.

An important idea for tutors (see Appendix 1) is that PISCES is an investigation of how to support teachers in making their own practice more investigative. As noted in the Preface, the idea behind PISCES is empowerment, and this applies to tutors, teachers and pupils. It is not our intention to deliver prescriptions or recipes, or rigidly define the role of tutors.

The feedback from the teachers was that, from their perspective, this was very much the correct approach - they were inquiring, as well as their pupils. The interviewer below was independent of PISCES and conduced a Focus Group with those teachers who were able to attend on a date after completion of the module.

> *Interviewer: I get the impression that if it had been something rigid and inflexible and prescriptive, then it would have been a bit of a contradiction in terms, when you're trying to -*
> *T6: It would have been really tokenistic just saying to the kids 'You're enquiring today but you're not because I'm giving you how you're going to do it and telling you what mistakes there are.' It doesn't mean anything.*
> *Interviewer: And in a similar way, if this CPD had been delivered in that fashion, right OK.*
> *T6: It's good that way because what's the point of teaching us differently from the way we've to teach the pupils? It's related to each other because it gave you a way of doing it.*
>
> *T1 It (PISCES providing tools for thinking, rather than recipes) was really useful, wasn't it? I think if they'd come in and given us a lesson plan, like some people I spoke to at the education conference were saying 'well, do they come in and give us a set of lesson plans?' I said, 'no, it's not about that, in a way it's almost like what we're asking our students to do. It's to have you thinking for yourself.'*
>
> *T2: There was so much freedom in what we could choose to do.*
> *T5: There wasn't really a right or a wrong answer.*
> *T2: They gave us a task and we went away and did it. Like I say, all of us came back with a different response or a different technique or whatever.*

None of us came back as having chosen the wrong thing to do because it was so open to do it. But we all followed the Inquiry path. That was the guideline, the science for that. We all used the tool.

Interviewer: Anything else? OK, would you recommend the module to your colleagues?
Chorus of: Yes.
Interviewer: Why?
T2: Because it just really got you get involved. It didn't just say 'here's the tricks, off you go'. It said 'find out the tricks and learn it for yourself and try it for yourself.'

As you will see from the above teacher quotes, 'tools for thinking' was a key aspect of PISCES that made it successful in empowering the teachers to make their practice more inquiry-based. These tools are discussed in chapters 2, 3 and 4. The tools enabled the teachers to conceptualise issues of inquiry, and to evaluate both their current practices and changes to it. Table 1 shows the model of empowerment used and Figure 1 shows how this operated over the PISCES sessions.

Basic outline of PISCES
Empowerment, *not prescription*
Accredited module giving empowerment to teachers: • To conceptualise issues of inquiry • To devise and implement own intervention questions • To try out answers to the questions in their practice • To evaluate the outcomes of their interventions

Table 1: Basic outline of PISCES (From Smith et al, 2011)

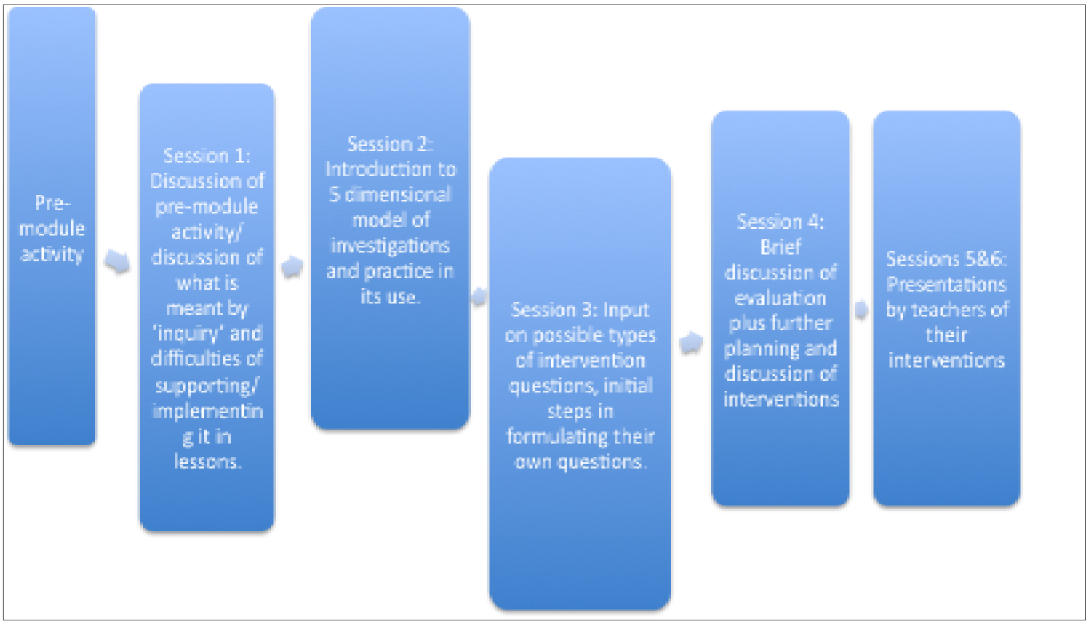

Figure 1: PISCES module sessions (from Smith et al, 2011). Our sessions were 90 minutes long.

Number of sessions and timing

The actual number of sessions required for PISCES depends upon the number of teachers involved, particularly for making the presentations in the length of session chosen. As we ran PISCES as a twilight option, end on to the teachers' working day, 90 minutes seemed quite enough to expect of them. However, there were advantages and disadvantages to this. A few sessions were quite tight for time: 2 hours would have been more comfortable. On the other hand, it did cause us to focus on getting through the planned schedule. At any rate, time of sessions is something that will have to be decided by tutors running PISCES in different contexts, according also to any adaptations they make to it.

The original timing between sessions is shown in the module outline in Appendix 1. There is no need for this timing to be followed exactly. These dates were built around original commitments and holidays of the participants and tutors. However, unusually severe weather meant that the final two sessions had to be postponed. We now think that this was a 'blessing in disguise,' as it gave the teachers more time to work on their practice and presentations. Therefore, we would recommend something like four weeks between session 4 and sessions 5 and 6. We also had sessions 5 and 6 on different days in the same week.

Depending upon the other workload of the teachers, weeks 1 to 4 could be weekly, fortnightly or more apart. However, the optimum seemed to be fortnightly, where other factors did not interfere. This gave time for teachers to think and to use the tools between sessions.

We managed to fit 4 presentations in to each session, plus awarding of the certificates in session 6.

PISCES outcomes

Those of us who watched the teachers' presentations (former teachers, now working as academics, development officer, other researchers) were very impressed with the range, imagination and quality of the teachers' interventions. The age range of the pupils involved was also significant – from primary 1 (age about 5) to fifth and sixth years in secondary school (ages about 16-17), showing that PISCES is applicable to teachers of all school stages. The teachers agreed that PISCES had been challenging in both requiring effort and engagement on their part and in making them think about their practice in new ways.

For achieving their high quality interventions, the teachers identified the important features of PISCES as being (Smith et al, 2011):

- The two models that helped them to think about issues in making their work more investigative, while also supporting their planning and evaluation of their interventions.
- The supportive comments from the group about their planned interventions.

- The fact that there was an expectation that they would do something in their practice and that they had to present on it.
- The learning from seeing the presentations of others and discussing together what they all had done.

The Development Officer also cited the fact that the module was accredited by a university as a significant draw when he issued the invitations across his local authority to teachers to participate. However, this may be a feature of Scotland, where CPD to teachers by universities is relatively rare.

The teachers also saw PISCES as a beginning, not something ending with the completion of the module, and were looking at how they might continue as a learning community. This ultimately resulted in them 'commissioning' the academic team to deliver a set of outcomes in a follow-up module that we called ARIES (Advanced Resources for Inquiry and Evaluation in Science). This is also an indicator of the success of the module for the teachers. They were prepared to be challenged further in thinking about their practice (Smith et al, 2011).

More background to PISCES and discussion of outcomes

More background and discussion of PISCES can be found in Smith et al, (2010 and 2011). Smith et al (2011) also incudes how we are beginning to conceptualise the learning of the teachers as Pedagogical Process Knowledge (PPK-knowledge of how to support processes such as inquiry and scientific thinking) and its relationship with Pedagogical Content knowledge (PCK) (for example, Kind, 2006; Park and Oliver, 2008; Shulman 1986)

Possible adaptations and or expansions.

Some features of PISCES that occur to us as perhaps leading tutors with different backgrounds and expertise to feel that they need to replace some material with their own are discussed at the appropriate points.

However, tutors may feel that they want to expand PISCES to cover topics not included in the original. Care might have to be taken not to expand the theory so much that teachers are overwhelmed and so find it difficult to come-up with intervention questions. There would be opportunities for follow-up modules after PISCES – a time when our teachers, at least, were beginning to actively engage with theory and welcomed more input of this type through ARIES. Nevertheless, tutors, based on their own expertise, and perhaps the perceived needs of their participating teachers and their readiness for this, may want to introduce extra relevant topics to more inquiry-based practice, say argumentation, because they have an interest and expertise in the relevant theory and practice. These could possibly be inserted between Sessions 2 and 3, giving the teachers more to draw upon in formulating their intervention questions. Having said that, we emphasise again that the module worked well for us in the present format and that we have no plans to develop it this way ourselves in our forthcoming diets.

Criteria for completion and accreditation.

Currently, our criteria for completion and accreditation are:

- The development of an inquiry-based, hands-on intervention for the science classroom.
- Submission of an artefact demonstrating the impact of the intervention on learners, colleagues, or the participant's own experience. The artefact may be of flexible format: video evidence for example, or more simply a brief written report.
- The delivery of a brief, individual presentation of the (early) impact of the intervention on you, your pupils, or colleagues to the programme group.

Upon successful completion of the programme participants will receive a certificate from Strathclyde University/S-TEAM in recognition of their work. S-TEAM currently working with other EU projects to establish a framework for recognition of PISCES and the equivalent course being run in other countries.

Chapter 2: Pre-module Activity

(See also, Appendix 2)

The pre-module activity was issued to participating teachers along with the module descriptor, about two weeks before the module began. The activity contained two thinking sub-activities, both aimed at supporting the teachers in beginning to think about what inquiry means for them and what constraints and difficulties might impact upon them. This was successful in making the discussion in the first session very fruitful. The teachers were not coming 'cold' to the first session but had already started to think about their own contexts.

The first sub-activity tried to begin to illustrate the difficulty in coming up with an all-inclusive definition of inquiry. The second sub-activity introduced the first of the two conceptual models – the Herron Model (Forsman, and Kurtén-Finnäs, 2010; Herron, 1971) of levels of inquiry. The aim here was to help the teachers to begin to think what changes they might make, and what difficulties need to be overcome, in making a topic of their own choosing more inquiry-based.

Otherwise, there seems little to add here that cannot be gleaned form the pre-module activity in Appendix 2. Issues and findings arising from the pre-module activity are discussed in the next two chapters.

Chapter 3

Session 1: Making Acquaintance and Discussion of Pre-module activity.

(See also, Appendix 3)

This session was divided as follows:

1) The tutors introduced themselves and explained the purposes of S-TEAM and the role of the module within it.[1] There is little point on elaborating on this here, as other tutors will do this in their own way and in accordance with their own reasons for running the module. If the reader is interested, more details can be found in Smith et al, 2010.
2) The teachers then introduced themselves, their subjects and their current status within their schools.
3) A group activity. The teachers divided into groups of 3 or 4 and used their thinking from the pre-module activity to discuss and provide 2 preliminary concept maps- one of inquiry and one of the difficulties of implementing more inquiry-based approaches. (See examples in appendix 3).
4) This was then followed by a whole group discussion, firstly of the concept maps, and then of the Herron model and the difficulties in towards more open investigations. This discussion turned out to be a very fruitful in setting the tone and direction of what was to follow.

However, we now know that the reason for the fruitfulness of the discussion in 4 above is the fact that the main tutor interpreted this discussion and fed back at the beginning of the next session. This may raise issues for both our own future deliveries of the module and for other tutors that are discussed in chapter 4.

There is another option here. Due to a half term holiday and other commitments of the tutors, the gap between Session 1 and Session 2 was several weeks. We were concerned that some momentum would be lost, unless the teachers were engaged in more thinking. We, therefore, asked them to read two academic articles (Kirshner et al, 2006; Hmelo-Silver et al; 2007 – in that order). The first of these basically argues that inquiry approaches do not work and the second is a rejoinder to this position. The second tutor issued the articles with some hints for reading them. He also led the discussion in session 2, utilising his experience of leading academic tutorials. There would, of course be the options of omitting this activity altogether or of choosing other articles.

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[1] There was one main tutor, but for the purposes of the pilot another researcher and the Development Officer were also present. However, the module does not require more than one tutor, unless there seems good reason to have more than one. Another model might be to have other people along at certain times, where their expertise would contribute, as in our own example above.

Chapter 4

Session 2: Summary of Session 1 discussion and S-TEAMS 5-dimensional model of investigations.

(See also, Appendix 4)

This is possibly the most demanding session, in terms of conceptual content, for the teachers. It also raises some issues for tutors, as it may take different directions with different groups, depending upon the outcomes of Session 1's discussion.

The following structure had been planned for the session:

1) Points from last session - 10 minutes – Main tutor (first part of PowerPoint in Appendix 4)

2) Discussion of significance of articles and S-TEAM discussion – 15-20 minutes – Second tutor (from Chapter 3, we noted that this activity is optional. It is also optional as to whether it is conducted by someone else, but this was good option for us)

3) S-TEAM's 5-dimensional model of investigations, including its dimension of scientific thinking–- 20-25 minutes – Main tutor (Second part of PowerPoint in Appendix 4 and following paper)

4) Applying this alternative model to science activities from pre-module activity or to new ones – 20 minutes – individuals or groups

5) Rest of session – General discussion.

However, most activities over ran and so there was little time for general discussion. This was only a minor issue, however, as the teachers needed more time to practice applying the 5-dimensional model. They were requested, therefore, to apply it to other activities from their practice. Blank copies of the table were issued for this (3rd document in appendix 4).

A few additional points can be made about some of these activities.

Points from last session

It was emphasised to the teachers that the presentation in the first part of the PowerPoint in appendix 4 was the main tutor's 'take' on what seemed to be the emerging and shared conclusions of the discussion. When asked for comments at the end, the consensus seemed to be that this take was correct. There are some interesting features for how this module went on.

First, a working definition of inquiry was that when pupils were asking question and getting or finding answers to them, they were inquiring. Inquiry occurs from the pupils' perspectives and is not a particular method of teaching, so much as an attitude on their part. Several teachers specifically focussed in their interventions to get the pupils to be more active in pursuing questions but, even where the focus was not on this directly, this conclusion seems to have been influential. This definition of inquiry seems to us potentially very useful, sweeping away at a stroke the often sterile debates as to how to define it from the teaching perspective. However, it does create a dilemma. Should we direct the discussion towards this as a conclusion? In our case, the main tutor was thinking along these lines and tried it out on the teachers during the discussion, who then seemed to adopt it. In fact, they seemed to forget that the suggestion had come from the tutor rather than the general discussion, so perhaps it is legitimate to do it this way. Of course, other groups may reject it but that could also be an interesting finding.

Clearly, we tutors need to be flexible here.

The other very interesting finding was the modification that resulted from the discussion of the issues involved in moving a learning activity up the Herron Model of Levels of Investigation (Table 2). The black (dark?) type shows the levels from 0

Level of inquiry	Problem	Material	Procedure	Answer
0	Given	Given	Given	Given
1	Given	Given	Given	Open
2 (Type A)	Given	Given, totally or partly	Open or partly given	Open
2 (Type B)	Given	Open	Open	Open
2 (Type C)	Partially open/ given as broad parameters are set	Open	Partially given (e.g. through previous experience of controlling variables, analogy with other experiments or forms of investigation) but open in sense not told what to do	Open
2 (Type D)	Given	Partially given by providing a range of material that includes (as a subset) what is required.	Open *from pupils' perspective (but given from teachers' as needs to use materials provided)*	Open
2 (Type E)	Open	Partially open – here's what we have in this school	*Open (but what about safety)*	Open
3	Open	Open	Open	Open

Table 2: Original Herron Model (black type) and modifications/additions (red Type) made by the PISCES' teachers.

to 3. The red (lighter) text shows the sub-levels 2C, 2D and 2E that were added as a result of session one's discussion. These sub-levels were not seen as a hierarchy within level 2. Rather, they were variations in line with particular topics, teaching aims, and constraints such as resources. The teachers again seemed to find this an accurate representation of their thinking and expressed a preference for it later (Smith et al, 2011). They also could be seen in their presentations to have been using it in both the planning and evaluations of their interventions. In fact, most placed their interventions somewhere on levels 2C to 2E.

However, this again raises an issue for subsequent running of the module. If the discussion does not lead to the tutor being able to feedback this (or other variations that arise because teaching contexts are different for other groups), do we show the teachers this extended version? This probably has to be a decision made by tutors according to their own assessments at the time.

Discussion of articles

The teachers had clearly read the articles and described it as 'like being back at uni.' The second tutor led the discussion and the general conclusions were that although Kirshner et al made some valid points, they were describing an academic rather than a real situation. Inquiry can work when the structures are in place and the pupils are actively engaged in asking questions and seeking answers. Our remaining feeling is that the activity was useful but not essential. It would be interesting to see if other readings can be found that have a stronger effect.

S-TEAM's 5-dimensional model of investigations

This is the second model introduced to the teachers to help them to think about their practice. It was intended to be less prescriptive than the Herron model, and to allow a more fine-grained reflection on what they were doing. The first four dimensions of the model are the results of thinking with 'teacher hats on' about what might be pedagogically useful questions about investigations. In our own delivery of PISCES, these dimensions seem to have been stable in that they did not provoke any negative comments form the teachers and there has been no perceived need to add others or to modify the existing ones. However, that does not exclude the possibility for the future or for others working in other contexts or cultures. The fifth dimension derives from the work of Feist (2006), and offers a model of scientific thinking. This dimension or model has also worked well with our teachers but there is again no suggestion that it is all-inclusive or final. What clearly emerged is that models such as this can be useful to teachers in thinking about and developing their practice.

However, it is important to emphasise that the model, despite our efforts to make it teacher friendly, is not immediately intuitive. An important lesson is that teachers need time to engage with the model and apply it to examples, and it is probably also worth indicating this to them. The feedback was that it is very helpful to them to have examples provided, as in the paper in the appendix, and that they only began to understand it when using these examples. What we witnessed was a growing confidence in the use of the 5-dimensional model as the teachers progressed into the follow-up module (ARIES). In PISCES they used both models in various combinations to plan and to evaluate their interventions (Smith et al, 2011).

Another important lesson is that one should not consider one's first go at completing the model for a lesson and topic as resulting in a final or definitive description. As one's practice and understanding develops, one can revisit these and see elaborations of the existing descriptions, see connections between dimensions or aspects of scientific thinking missed before, and so on. Keeping these shows how one's thinking has developed. This is true, even for the tutors. We can now see possible elaborations and connections that can be made to some of the examples provided. We have not changed them, however, as that may make them appear more intimidating to the teachers.

As regards the scientific thinking part of the model, the paper makes two points clear. First, the reason for using the term 'aspects' rather than 'skills.' However, Scottish teachers, at least, are obviously happier with the term skills. This did not seem to lead to the narrow picture of their development that we feared. Secondly, not every aspect of scientific thinking can be expected to be involved in every classroom activity. However, as we did when we worked on our examples, the teachers also found that their lessons were, potentially at least, more supportive of scientific thinking than they had imagined.

One important issue for prospective tutors is the format of the presentation. You will see from the PowerPoint in Appendix 4 that the main tutor drew on an example from his own practice as a teacher to illustrate the model. This example could be narrated as a story where things went wrong initially and, perhaps, created some credibility for the tutor because he had lived through it. Obviously, tutors with teaching experiences of their own that tell interesting stories can draw upon these. A possible question for tutors who do not have such experiences like this is, 'What example do I go with?' This one, although it is not mine, or one of those from the paper?' Or another possibility is to observe a lesson, as in the appendix to Smith et al (2010), and to use the observations from that. The aim would be for the tutor to feel comfortable in describing the model and giving an example of its use.

A further point is worth mentioning. Whether by chance or design, we do not know, none of the teachers designed their interventions around scientific thinking or its aspects as being targets. We now believe that this was right and was a major factor in the successes of their interventions. This continued into ARIES. Treating the aspects of scientific thinking as targets in themselves would probably lead to the same sort of 'tick the box' treatment we feared and tried to avoid by calling them 'aspects' in the first place. This may be due, we cannot be certain from the data we have, to the approach we suggested to intervention questions (next chapter) that bases them upon a dissonance between what one values and wants to do and the values and actions one's practice actually exhibits. Most of teachers' intervention questions can be interpreted in this way to a degree (next chapter) but the focus group discussion did not discuss this, so that might be us reading things that are not necessarily there. What is clear is that the intervention questions were focussed on issues of inquiry such as getting pupils to ask questions, be more independent of the teacher through requiring less direction, increase engagement and ensure that course content was mastered correctly.

At any rate, the teachers, from the data, seemed to use both models to analyse what was happening. The Herron model seems to have been used more as a planning tool and as an evaluation of what kind of practice (level of investigation) was used in the intervention. In that sense, the levels of investigation acted as a target to a degree. The 5-dimensional model seems to have served more or less as an analytical tool before and after the intervention, and this seems now to us to be its best use, at least in the initial stages. Decisions as to whether practices need to be devised to support aspects of scientific thinking that, over time, seem to be less common, would be for teachers to make once they had built up some data on this.

Overall, the models were very successful in their aim of empowering the teachers to think about their practice and to evaluate their interventions. How did they come about their intervention questions?

Chapter 5

Session 3: Towards intervention questions

(See also, Appendix 5)

We are not sure where the term 'intervention questions' originated from – the teachers, the development officer or the tutors. However it originated, it is a term that we all adopted easily. However, other terms may be used. The term basically refers to questions of the type 'What am I going to do to make a change in my practice?'

What prospective tutors need to be aware of is that the approach (Living Theory Questions, for example, Whitehead, 1989, 2000) to formulating intervention questions that was presented to the teachers in this session was one favoured by the main tutor due to earlier work (Brownlie et al, 2007, Smith, 2002). Again, tutors may wish to draw more on their own experience in suggesting approaches to intervention questions (or other term if preferred) to the teachers.

The planned agenda for Session 3 is below.

4.30 - 4,45 Individual sheets working on first draft of aim and intervention question

4.45 - 5.00 Input on developing intervention questions – Main Tutor

5.00 - 5.15 Pair-work - talking about and developing intervention questions

5.15 - 5.30 Whole group discussion of questions etc.

5.30 - 5.45 Preparation of individual (or, perhaps, group) flip chart sheets showing aim, intervention question, who intervening with, how it is planned to do it, and why.

5.45 - 6 Time for everyone to go round each chart and give feedback (feedback given in writing on the chart).

Individual working on first draft of the intervention questions.

The first two sheets in Appendix 5 were given to the teachers on arrival. This was partly to help them to begin to think about their intervention questions, and partly to occupy the teachers who arrived first. A pattern had been developing of staggered arrivals. On reflection, the first sheet was probably given too early (that is, before any input on intervention questions) but the second sheet was helpful in focusing the teachers' attentions on where they might do something.

Input on developing intervention questions

This is outlined in the PowerPoint in Appendix 5 and is, hopefully, fairly clear to the reader. What is, perhaps, worth pointing out again that the attraction for this approach for the main tutor is that it gelled with his experience as a teacher. There were many times that he felt the experience that Whitehead describes as a 'living contradiction' (valuing one thing but doing something that negates that value) and asking the question of ‘How do I work through this?’ However, the opening slide suggests another form of question that is currently used by some CPD deliverers in Scotland – ‘What benefits will my pupils get if….?’ Teachers were given the opportunity to choose and so tutors should have that as well – you may have other forms that you prefer. What seemed clear was that the teachers having a question formulated by the end of this session (the following activities also helped this) was an important milestone for them, although one changed his mind later on further reflection and consideration of the 5-dimensional model.

Also worth noting is that the tutor was able to incorporate an earlier comment from one of the teachers (slide 4) to illustrate the idea of a living contradiction. You will also note that the main tutor prefers formulations of questions that imply *working with and supporting* pupils rather than technologically sounding questions implying *manipulation of, or working on, pupils.* As pointed out, we have no comments from the teachers on the influences of these stances upon their thinking. The questions the teachers came up with favoured the ‘how?’ form of question. Some of these, but not all, are also obviously consistent with the ‘working with’ conception. We wondered whether including the question in this handbook was a good idea and have decided on balance not to do so. There are two main reasons. Firstly, without the details of the actual work of the teachers, the questions may seem a bit bland to the reader. A description of all of this would make the handbook even larger and prolonged in production, although it is the intention to publish this material eventually. Alone, the questions certainly do not convey the range of thought and innovation in practice that followed. Second, and perhaps more important, we do not want to create any expectations for what the teachers will do. To be as consistent as possible with its rationale of empowerment, each run of PISCES should, in our view, be an individual affair, in which the teachers feel free from comparison of output with others who have taken it at different times. This is difficult to achieve, as the main tutor has experienced as another PISCES module began, and in the other material in this handbook we feel that we have gone as far in facilitating comparisons as we wish in this context, for the moment at least.

Developing intervention questions

Once again, we were running short of time, so the next three points in the agenda took the following form. We still had some time for the teachers to work in pairs and discuss their initial ideas (from before the presentation) and their thinking now. They did not feel the need for the whole group discussion (and time was short), so they moved on to an activity that they later told us had been very valuable, supportive and encouraging.

Each teacher was given a sheet of poster paper and asked to use the headings, ‘Aim,’ ‘intervention question,’ ‘who,’ ‘why,’ ‘how,’ and ‘when’ to describe their current thinking about what they were going to do. When these were completed, everyone went round looking at each sheet and left one written comment or question. These were written on post-it (sticky) notes. The teachers used one colour and the tutors used another, so that the teachers could distinguish these two sources. There seems no reason to doubt that teachers on subsequent modules will not also find this a very worthwhile step.

Chapter 6

Session 4: Discussion of Evaluation and further thoughts about intervention questions

This was a fairly relaxed, round-table session. We had intended to deliver some formal thoughts on evaluation but, on the advice of the Development Officer, this was dispensed with. However, the teachers did ask for some general discussion of evaluation. Another group in S-TEAM (Gröschner et al, 2010) has developed a compendium of indicator instruments. Two of these from Danielowich (2007) (cited by Groschner et al, 2010, pages 44 and 45) provided some items that the teachers could ask themselves. It was not expected that the teachers would answer these questions, just that they would help their thinking as the reported on what they had done.

- How did the students respond to your lessons? What happened that you predicted would happen? What surprised you and why?
- Was the lesson successful? How are you defining success?
- Did students that typically don't respond as much as you want respond better? Why?
- If you had to do this lesson again with this group of students, what would you do differently and why?

It was also pointed out that they had the conceptual tools from this module to use in their evaluations, that they could collect observations about the pupils, that they could ask the pupils for for comments, that they could devise a simple questionnaire and they could use the pupils' work as evidence. In practice, the teachers seemed mainly to rely on various combinations of these latter methods.

The rest of the session was left to the teachers. They talked about their interventions to each other and to the tutors and browsed a number of resources that had been provided. These comprised a number of books on science teaching, for example, Ross et al (2010) and Wellington and Ireson (2008) because they seemed to us to be up to date and rich in examples of teaching. Other tutors could find other resources but we now feel that this might need some rethinking to find resources that are more obviously relevant to the teachers. A resource that they did find very useful, which they asked if their local authority could purchase, was Black and Harrison (2004). The feature that they liked about it was its sections on questions and dialogue. However, as it is little more than pamphlet sized, it was also easy to digest quickly. More resources of this type would be useful. However, as noted, the teachers went on and carried out impressive interventions with what was provided. Perhaps the resources are a more minor factor in the overall support provided by the module.

In the focus group, the teachers emphasised the learning from each other that went on in this and the earlier discussions in the module.

Chapter 7

Presentations and accreditation

As explained earlier, it is not intended here to go into detail into the teachers work. If some insight is required a short video clip of excerpts from 3 teachers' presentations can be obtained by emailing Allan Blake (see author information). Once again though, we emphasise that the responses of the teachers to the module in the quality of interventions they carried out all exceeded our expectations, and we feel that we are a discerning audience. We have to acknowledge that they were a self-selected group in that they volunteered for PISCES, but that does not detract in our view from the results. It does, however, suggest that this might be a module only for those keen to take part and the teachers did make this point in the subsequent focus group.

The presentations featured interventions with classes over a wide age range: Primary 1 (age about 5) to Secondary 5/6 (ages 16/17)

Another point is that the teachers found the presentation sessions valuable as they:

- It emphasised to them the clear expectation that they were expected to do something in the classroom and report on it and gave them the motivation to do so. They contrasted this with other CPD that gave them 'tips or recipes to try' but which 'fell by the wayside' in the busy reality of school days.
- They learned a lot from each other's presentations that could be added to what they had learned in the earlier activities and discussions.

In Chapter 1, we presented the accreditation criteria we started out with. We have retained these for the future because they offer some flexibility to the teachers. However, probably because presenting to the group was a requirement of the module, all the teachers used their presentations- rather than a written report, video, etc- as the artefact to be submitted. We suspect that this is likely to be the norm.

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Appendix 1

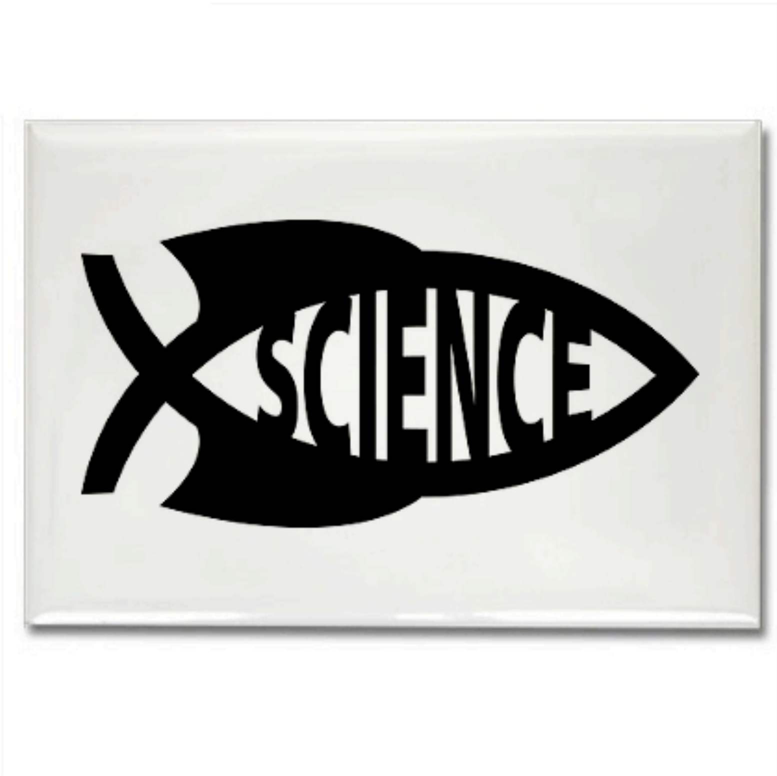
Module Descriptor

S-TEAM
FIRING UP SCIENCE EDUCATION

PISCES

Promoting Inquiry in Science Classrooms in European Schools

Module outline



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The Scottish Context

Curriculum for Excellence (CfE) promotes the use of inquiry-based learning in the Sciences. Learning and Teaching Scotland's companion guide, *Curriculum for Excellence: Sciences, Principles and Practice* states that:

> ...experiences and outcomes in science provide opportunities for children and young people to develop and practise a range of inquiry and investigative skills, scientific analytical thinking skills, and develop attitudes and attributes of a scientifically literate citizen.

Science: A portrait of current practice by HMIe (2008) reviews the extent to which contemporary practice in science teaching is successfully promoting the four capacities of *Curriculum for Excellence*, and it too is clear that practical, inquiry or investigative learning activities are 'key to developing successful learners in science'. However, drawing on the evidence of the inspection of primary and secondary schools between 2004 and 2008, the portrait is reserved about the depth or breadth of the provision of practical inquiry work in Scottish schools, conceding that in 'secondary schools, too often, young people were not sufficiently active in their learning' and that children's 'skills of scientific investigation were too limited' in primary schools also.

The European Context

A similar situation applies in many countries across Europe. S-TEAM (Science Teacher Education Advanced Methods), a project in 15 countries, has found that many science teachers may use investigative methods in their practice, at least sometimes, but they also experience many obstacles. These include time, the structure of the curriculum, forms of assessment that focus on content and, perhaps, their own lack of experience of investigations, either in their own learning or through not having worked themselves in science. There may even be resistance at times from pupils or their parents. Even for those teachers who wish to use a more investigative or inquiry-based approach in their practice, there are often formidable problems to overcome.

The module

This module is designed to help teachers work through the particular problems that they encounter in their own settings. The focus and format has arisen through discussion with a collective of East Lothian Science Teachers. When we ran it for the first time, we anticipated that further development to the module would be required to better respond to participants' individual circumstances. There may be unforeseen challenges along the way, which might require adaptation to your own circumstances. However, we hope that this will remain a programme, which, instead of being prescriptive, attempts to be empowering to both teachers and, through them, their pupils. You can, therefore, evaluate the module against the following question:

> *How does this module empower teachers (or student teachers) to further the engagement of their pupils in inquiry-based learning?*

Although the module does not attempt to be prescriptive as to what teachers do in their practice – it does not say, "Do inquiry this way" – it does however present a *structure for empowerment* based on a number of learning outcomes.

Outcomes

As a result of taking part in and contributing to the development of this module, it is anticipated that participants will have begun to develop and apply collaborative understandings of inquiry-based learning in science through interventions to classroom practice, by working towards:

- theoretical and critical understandings of inquiry through reading, discussion and analysis;
- an applied understanding of inquiry through the design and implementation of a practical, hands-on intervention in the science classroom;
- the foundation or enhancement of the classroom environment to accommodate inquiry;
- a shared capacity for supporting teachers in developing their understandings of inquiry-based learning in science (leading, in time, to the reproduction of programme outcomes with colleagues in school and teacher education institutions).

Sample Seminar Schedule

The module consists of five or six seminars, each of about one and a half to two hours, to be run either as twilight sessions or at other convenient times. Participants will be required to complete a pre-module activity ahead of the first meeting. The activity is designed to explore the levels of inquiry that might exist in an example from participants' current practice, as well as introduce an approach to analysis and reflection that will prove useful during the course as well as beyond.

We suggest that there should be an interval of at least two weeks between sessions 1-4, and four weeks between session 4 and the final presentations. These intervals can, however, vary according to local circumstances. The optimum number of teachers in the group should be between six and twelve.

Session one	Introduction: referring to (e.g.) the statement of scientific literacy that underpins *A Curriculum for Excellence in Science*, a lively discussion and analysis of participants' pre-module activity findings will kick-start the metacognition of processes and practices in inquiry-based teaching and learning in science. This can be adapted to participants' local curriculum documents as required.
Session two	Scientific Thinking: participants will be introduced to the S-TEAM project's five dimensional model of scientific inquiry. Task: following this session, participants will be asked to complete a record of a classroom lesson or topic that took place. The aim will be

to consider to what extent this activity supports scientific thinking, and any other issues that the model of investigation suggests.

Session 3 Designing an Intervention: participants will discuss and begin the work of designing an intervention using inquiry (or alternatively advanced) methods for use in their own practice. This will be informed by the analysis of the examples from participants' current classroom practice, using the Scientific Thinking Tool (based on the fifth dimension of the investigative model).

Session 4 Supporting an Intervention: in support of putting into effect participants' individual interventions, the group will provide collaborative critical friendship.

Session 5 Conclusion I: presentation of the preliminary results of participants' interventions to the cohort. (Note: if convenient, sessions 5 & 6 can be combined into one longer session)

Session 6 Conclusion II: continuation of presentations, if the number of teachers requires this session.

The sessions represent approximately 9 hours of participants' contact CPD time, but the tasks required for completion of the programme may denote additional CPD hours. The exact number of hours can be determined locally.

Criteria for Completion

- The development of an inquiry-based intervention for the science classroom.
- Submission of an artefact demonstrating the impact of the intervention on learners, colleagues, or the participant's own experience. The artefact may be of flexible format: video evidence for example, or more simply a brief written report.
- The delivery of a brief, individual presentation of the (early) impact of the intervention on you, your pupils, or colleagues to the programme group.

Upon completion of the module, participants will receive a certificate in recognition of their work. The module is part of a wider qualification scheme, which is being promoted by S-TEAM at European level, and we hope that participants will be able to complete further modules as they become available.

Appendix 2

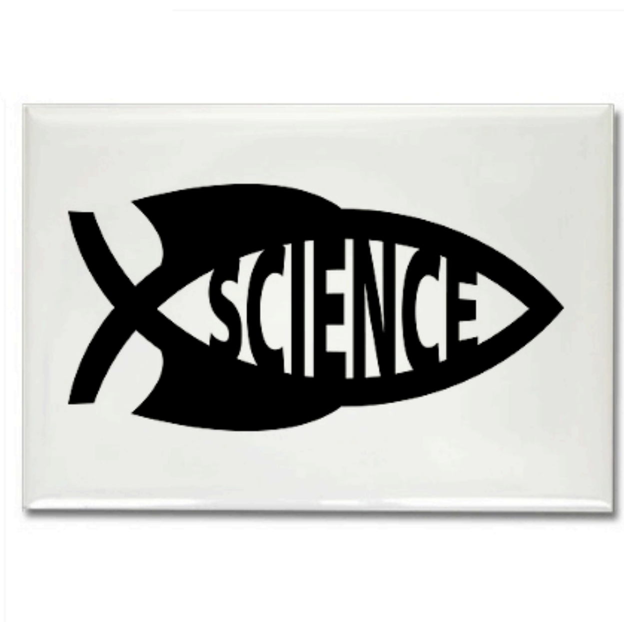
Pre-Module Activity

S-TEAM
FIRING UP SCIENCE EDUCATION

PISCES

Promoting Inquiry in Science Classrooms in European Schools

Pre-module Activity



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Introduction

Perhaps the best way to sum up the intention of this module is that ***it seeks to be helpful to teachers investigating how to make their teaching of science more investigative.*** It is not a top-down prescription on how to do investigations. It is an attempt to provide a structure that helps teachers solve problems they have identified themselves. It aims to support teachers to change their practice so that they and their pupils are engaged in their science education in a more investigative way. It is recognised that the meaning of '*changing their practice so that they and their pupils are engaged in their science education in a more investigative way*' may be different for different teachers working in different schools, local authorities and national cultures. It is for that reason that we see the structure of this module as a structure for empowerment.

However, we cannot bring a structure to teachers without having some background ourselves in the issues involved. Therefore, the purpose of this pre-module activity is to begin to make this background clearer to you. This background, and the theoretical stance we build around it, is itself the subject of investigation and may change as we gain experience of working with teachers in this way. At the risk of over elaboration, we are investigating how to provide a structure that helps teachers to investigate how to change their practice so that they and their pupils are engaged in their science education in a more investigative way. The best way, we feel, to make our background clearer to you is to involve you in the same question that we have – what might it mean to make our teaching more investigative?

What might more 'investigative' mean for you?

One key to understanding the thinking that lies behind this module lies in the possibility of *making the teaching of science* ***more*** *investigative*. It is possible to debate and define what constitutes investigative science teaching, but it is surprisingly difficult to look at classroom activities and say categorically that they are not investigative in some way. There are different kinds and levels of investigations. Some may be what we typically think of as investigations because the pupils are working on questions they have chosen themselves and are engaged more or less independently of the teacher in designing the method being followed in attempting to find answers to that question. Based on the definition below, that would be a very open investigation.

Open investigations are characterized by the following features:

- The educational process is less teacher directed,
- More planning takes place in the classroom,
- More focus is placed on the scientific process,
- There are more topical discussions between students in the classroom,
- The students themselves are more active and initiate more ideas of their own. (WP6, S-TEAM, 2010a, page 10, emphasis added)

Enabling pupils to engage in very open investigations, on occasions at least, may be the ultimate aim of making science teaching more investigative, but it is not difficult to imagine a whole range of activities that could still be called investigative, even though they are less open. For example, what do you think of this definition of a closed investigation?

Closed investigations are characterized by the following features:

- *The educational process and content are more teacher directed,*
- *Some planning takes place in the classroom,*
- *Focus is placed on the scientific process in relation to particular content,*
- *There are discussions between students and teachers in the classroom that relate to the scientific process in relation to the particular content,*
- *The students and teachers together are more active and negotiate ideas but the teacher's goals are prominent in the discussion.*

Or this one?

Non-investigative teaching is characterized by the following features:

- The educational process is very teacher directed,
- No planning takes place in the classroom, the teacher has designed a script for the lesson,
- Little focus is placed on the scientific process but much is placed on delivery of content,
- There are few discussions between students and teachers of the content in the classroom,
- The students initiate no ideas of their own

Do you agree with these definitions? You may want to write your own alternatives in the page following for either these ones or, perhaps, for semi-closed investigations or semi-open investigations. Alternatively, you might like to write as wide a range as possible of definitions by altering different components of the ones above and see what the outcomes look like and whether they can be applied to the range of things you do in the classroom.

My definitions

Clearly, there is a range of possible definitions of classroom learning encompassing many variations between those that eliminate investigative activity entirely to those that are investigative but in a closed way, to those that are fully open. Agreeing on a final definition is also difficult but you might now be formulating your own position. Since you are on this module because you want to make your science teaching more investigative, that could mean in one sense, that the definitions don't matter. You don't want to be in a situation where you eliminate investigative activities completely but, more specifically, you do want to be able to think about your teaching and ensure that you are not missing opportunities to be investigative. To help with that, we will introduce a model in the fourth session of the module.

Since, for us, an important factor in developing investigative activity in teaching science involves scientific thinking, the model includes a version of that process. The other components of the model allow you to consider the goals, openness, forms of pupil involvement and issues of structuring the investigation that a consideration of the above definitions raises.[1] In empowering the development of opportunities for investigative activities, the module will also recognise the role of emotional and relational factors in creating pupil enthusiasm and creative classrooms, which might also be expressed in the correlation between positive emotional engagement and more open-ended thinking.

In the meantime, however, you might like to consider the following model that relates to scientific thinking.

Level of inquiry	Problem	Material	Procedure	Answer
0	Given	Given	Given	Given
1	Given	Given	Given	Open
2 (A)	Given	Given, totally or partly	Open or partly given	Open
2 (B)	Given	Open	Open	Open
3	Open	Open	Open	Open

Table 1: Levels of inquiry in the science laboratory (S-TEAM, 2010a, page 15

This model uses the idea of levels of inquiry. For example, level 0 can be thought of as eliminating inquiry because the teacher gives everything – the problem to be investigated (say, do plants need carbon dioxide for photosynthesis?), the materials or apparatus to be used, the procedure to be followed and the answer. The answer might even be given in advance. How? Say by entitling the activity as "Experiment to show that plants need carbon dioxide for photosynthesis." The title tells the student the answer to the question. In fact, realistically, just asking the question, "Do plants need carbon dioxide for

[1] Those of you who at this point recall the module descriptor will have noted that it includes the outcome that you will show an applied understanding of inquiry through the design and implementation of a practical intervention in the science classroom. That is not to exclude other ways of making teaching more investigative.

photosynthesis?" might be enough to give the students the answer since we probably don't ask many questions of this type, then carry out an experiment to test them, when the answer is going to be negative.

So here is an activity that you might like to try before starting the module. We think that you would find it useful.

Activity.

Take either the above carbon dioxide and photosynthesis activity and/or choose one of your own from your own subject or interest. Formulate it as a level 0 activity as follows

Name of activity	**How it would be structured as a level 0 investigation**			
	How the problem would be set?	**What materials would be used and how would they be provided?**	**How the procedure would be given to the students?**	**How the answer would be given?**
Carbon dioxide and photosynthesis (if you choose this)				
Of own activity (if you choose this)				

Now, how would this activity be redesigned to become a level 1 activity?

What teaching and learning issues, if any, would this raise and how might they be overcome?

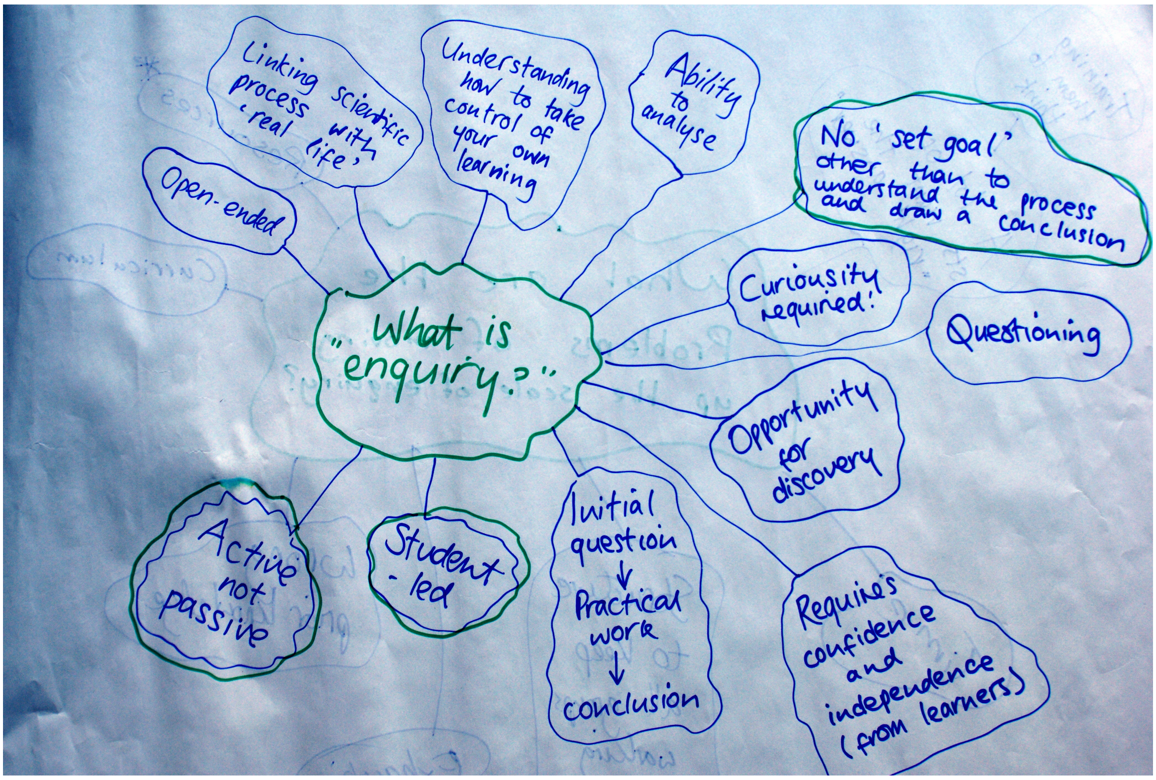
Now how might it be redesigned to become a level 2A activity?

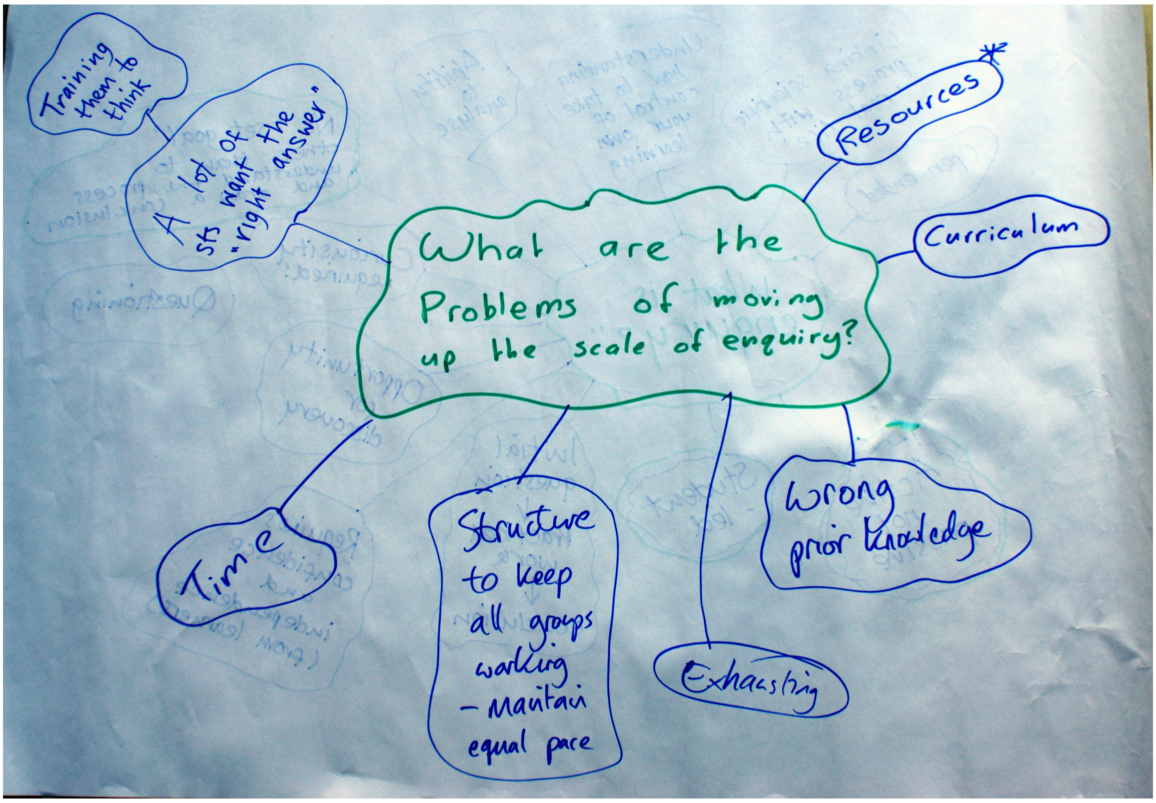
What teaching and learning issues, if any, would this raise and how might they be overcome?

Repeat the above questions for the remaining levels. Can this particular activity be designed to be completely open? If not why not? If yes, why don't we always do it this way?

Appendix 3

Examples of Concept Maps


"What is enquiry?"
Linking scientific process with 'real life'
Understanding how to take control of your own learning
Ability to analyse
No 'set goal' other than to understand the process and draw a conclusion
Open-ended
Curiousity required!
Questioning
Opportunity for discovery
Active not passive
Student-led
Initial question ↓ Practical work ↓ conclusion
Requires confidence and independence (from learners)


What are the Problems of moving up the scale of enquiry?
Training them to think
A lot of sts want the "right answer"
Resources
Curriculum
Time
Structure to keep all groups working – maintain equal pace
Exhausting
Wrong prior knowledge

Appendix 4

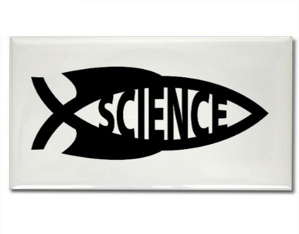
Materials used in Session 2

- Session 2 PowerPoint

- Paper outlining 5-dimensional model and examples of it use

S-TEAM
FIRING UP SCIENCE EDUCATION

Pisces



Week 2
Colin Smith

East Lothian Council

University of Strathclyde Education

From week 1?

Pupils' perspective

A lesson is an investigation from the pupil's point of view if, during it, they are exploring their own questions or having their own questions answered.

Some points arising

- Teachers can answer pupils' questions when they judge it to be the best strategy.
- Teachers can use pupils' questions (curriculum related or not) to instigate further inquiry activities in pursuit of teaching goals – engagement, KU or inquiry skills, or combination,
- Within an experimental investigation, teachers can give specific experimental methodologies once pupils see the need for them. E.g techniques required for photosynthesis investigation
- A key problem - to get the pupils to ask the questions we want them to ask so lessons become attempts to answer their questions. Wondering? Other strategies?

Enhanced model of levels of inquiry - varieties of level 2

Level of inquiry	Problem	Material	Procedure	Answer
2 (Type A)	Given	Given, totally or partly	Open or partly given	Open
2 (Type B)	Given	Open	Open	Open
2 (Type C) *Is this us? Is this really what research is like?*	Partially open/ given as broad parameters are set	Open	Partially given (e.g. through previous experience of controlling variables, analogy with other experiments or forms of investigation) but open in sense not told what to do	Open
2 (Type D)	Given	Partially given by providing a range of material that includes (as a subset) what is required.	Open *from pupils' perspective (but given from teachers' as needs to use materials provided)*	Open
2 (Type E)	Open	Partially open – here's what we have in this school	Open *(but what about safety)*	Open

Some thoughts

- Existence of level 3 appears questionable in schools
- Level 2 can be thought of as different forms of investigation with different teaching goals. They become investigations when given question(s) becomes pupils' own question(s)?

Making more investigative?

Those who chose other examples (not photosynthesis) in pre-module activity seemed to succeed more in moving the activity "up the levels."

Helpful?

- Thinking about reasons for this may be helpful in planning an intervention in this module.
- Also, thinking about forms of investigation in relation to your teaching goals – perhaps, a "lower" or more closed level/form may be appropriate to some goals (developing certain skills, for example, that can be used later in more open investigations)
- Planning sequences of investigations, not investigations in isolation? Type 2C a model?

A tool for thinking about and shaping investigations or investigation sequences

The model

- 5 dimensions
- 1-4 Complementary to but different from last weeks model.
- Doesn't seek to categorise but to aid reflection and description.
- 5 adds a dimension that models scientific thinking

Dimensions 1 to 2

Dimension of Investigation	Some Teaching Questions That Arise
1) Origin in understanding. That is, does the question behind the investigation derive from pupils' thinking inspired by everyday understandings, or does it derive from pupils' thinking inspired by new scientific understandings they have developed or a re developing in the coursework?	a) Can I justify pursuing it within the content requirements of this course? If not, have I got time to pursue it for other reasons (e.g. 1b, 1c and 1d or 2b, b) What are the consequences, such as continued misconceptions, if I leave it? c) Can I justify pursuing it because it is likely to promote engagement? d) What aspects of scientific thinking (dimension 5) would be supported by this investigatio n ?
2) Origin in goals. That is does the question behind the investigation arise from students' and /or teachers' goals?	a) Did I instigate this investigation, or did the pupils, or is it the result of a jointly felt interest? b) Did I instigate this investigation as a challenge to pupils' pre-understandings? c) Did the pupils instigate this investigation out of interest and will it promote engagement? d) What aspects of scientific thinking (dimension 5) would be supported by this investigatio n ?

Dimensions 3 and 4

Dimension of Investigation	Some Teaching Questions That Arise
3) Control of the investigation. That is, who will direct the activity – the students, the teacher or will control be shared in a partnership ?	a) Will the pupils be able to devise unaided a suitable investigative strategy, or do we devise it together, or do I suggest the strategy to them? b) Am I controlling the investigation to ensure coverage of course aims and ability by the pupils to deal with assessment requirements? Can I achieve this without exerting this degree of control? c) (Related to 'a' above) What aspects of scientific thinking (dimension 5) do they need to devise and carry out an investigation of this question and when and how do I put scaffolding in place when these aspects are absent or need help in developing? Are some of them only able to be practised when pupils have a certain amount of control?
4) Degree of openness of the investigation That is, how limited is the investigation in either the solutions that the students will come to, and/or in the scope of experimental, observational or text-based (including Internet) research required ?	a) Is the investigation question closed enough to be answered quickly and with a reasonable certainty that the pupils will come to scientifically accepted conclusions? b) Is the question too open to be fitted in to the constraints of time and course requirements? c) In open and, possibly also, closed investigations, how will I monitor the development of pupil's understandings and challenge any initial and/or developing alternate or misconceptions? d) What aspects of scientific thinking (dimension 5) are supported by closed and open investigations? Are some of them particular to certain types of investigations?

Dimension 5

Dimension of Investigation	Some Teaching Questions That Arise
5) Aspects of scientific thinking used in the investigation	a) What aspects of scientific thinking would be supported by this investigation and do I need to do other types of investigation to e nsure all are practised effectively?

The Eye Project

- An S2 project
- A mix of some ‘well-behaved’ pupils, some slightly rebellious pupils, some very rebellious pupils and some with support for learning needs.
- Support for Learning teacher (ex physics teacher) giving quite a lot of time to this class in various subjects.
- Opportunity to experiment

Model of understanding

- Simple model of understanding was behind the project
- Based on Entwistle's research into conceptions of understanding and Mayr's writings on biology (refs at end)
- Unconnected, descriptive and explanatory forms of understanding.

Unconnected understanding of the eye

I know….

1 know….

I know….

Write as many of these as they like

Begin connecting by looking for points that go together

Descriptive understanding of the eye

Labelled diagram of the eye

Asked to think about how what they already know/ believe fits with this

Part of eye	Description of what it does

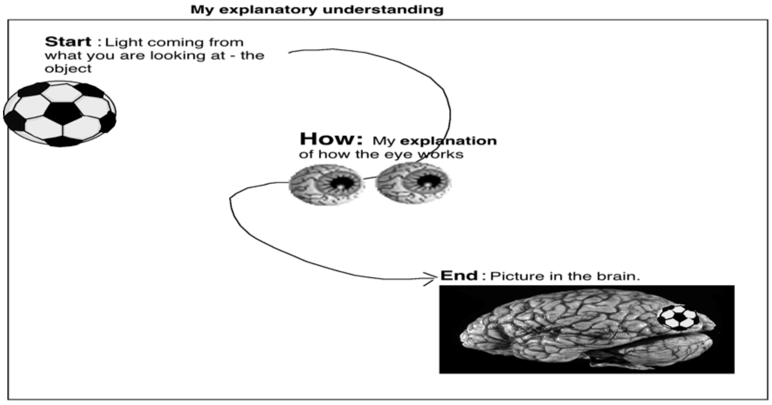
Getting to my explanatory understanding.

In the last lessons, you started by considering what you **knew** about the eye, but **had not really thought about in a joined up way** – what we are calling **unconnected understanding**.

Then you started to build up a **descriptive understanding** – you can name the parts of the eye and what they do. With this type of understanding, you can **describe how the parts of the eye fit together** and **what they do**.

Now, to complete the process, it is time for you to build your **explanatory understanding.** With this, you will be able to **explain how the eye works.**

My explanatory understanding



You have **1 period** to produce an **explanation of how the eye works**. As the diagram shows, you start with light coming from what you are looking at and explain how a picture of it occurs in the brain.

To help you, remember what is in the following box.

In your explanation, you should be able to show:

☐ Check • that you know the names of the parts of the eye and where they are.

☐ Check • that you know what the parts you can name do.

☐ Check • that you can **explain how** the light coming from what you are looking at ends up as a picture in the brain.

It would be **a bonus** if you can **explain how** the parts of the eye do what they do - eg. how the iris cotronls the light going into the pupil, how the muscles change the lens to focus the light, and so on. **The more of this you can do, the bigger the bonus AND THE BIGGER YOUR UNDERSTANDING.**

You can **choose** to do the explanation in any of the following ways.

- You can write it in the usual way – illustrated with diagrams if you wish.
- You can do it as a cartoon script.
- You can speak it – we have a few tape recorders so that we have a record.
- You can do a flow chart.
- You can write a poem.
- You can make up a rap song.

Problem!!!!

“Superman theory of vision” spread uncontrollably through a large proportion of the class”

Note

- Pupils were using thinking that can be described as scientific - e.g. coordinating their theory with evidence, thinking about cause and effect, collaborating in thinking.
- Were, however, basing it on everyday experience, not the descriptive understanding they had built up

Our challenge

- Devise an experiment to support your theory and to disprove ours.
- Darkroom experiment
- Agreed we couldn't see anything when in total darkness.

The value of experiment?

- Came closer to aligning their understanding with the scientific view by accepting that the scientific explanation fitted the data better than their own explanation.

Scientific Thinking (Adapted from Feist, 2006)	
Aspect	**What it involves**
I observe with any or all of my senses as required	Fairly self-explanatory – all senses (not just vision) may be used as appropriate to input information
I categorise what I observe as things and events	Classifying information from observations into meaningful concepts or systems of concepts
I recognise patterns in the categories of things and events	Seeing patterns of relationships between different things and events the classified information above refers to (E.g. Thing A is always found with Thing B. Event Y always follows Event X)
I form and test hypotheses	Arises initially from pattern recognition. Begin to expect world to behave in certain ways and test these expectations
I think about cause and effect	Arises initially out of pattern recognition and/or hypothesis verification (e.g. recognition of pattern that Y follows X or verification of this as a hypothesis leads one to think about causes). More sophisticated when one realises that co-variation is necessary, but not sufficient, for causality.

Scientific Thinking/scientific mind (adapted from Feist, 2006)	
Attribute/skill	**What it involves**
I effectively support theory with evidence	This includes avoiding confirmation bias, not ignoring disconfirmatory evidence outright, avoiding distorted interpretations of evidence to fit preconceptions and distinguishing examples from principles.
I visualise	Visualisation in scientific thinking can take various forms including thought experiments, models and diagrams, graphs, charts and tables. These tables, for example, comprise an attempt in visualising scientific thinking.
I am aware of my thinking and control it	Although beginning in observations, scientific thinking is not sensory bound but can make use of abstract concepts and theories. Scientific thinking involves being aware of these concepts and theories so that they can be challenged and modified. Along with this awareness is also an awareness of the thought processes being used and directing them towards goals such as understanding.

Attribute/skill	What it involves
I use metaphor and analogy	Analogy – seeing how something (target) is like something old (source). Metaphor – an 'as if' comparison. Think about X as if it was Y. Both of these are used in scientific thinking in the process of hypothesis and theory formation, thought experiments, creativity and problem solving. In thinking about experiments in one context, we also may use analogies based on experiments from other contexts to design the experiments or to fix problems we are having with it. Analogy and metaphor also provide useful constraints to solutions to problems by focussing strategies
I use the 'confirm early-disconfirm late' heuristic	In practice, this may be rarely used in school science but is included here for completeness. Apparently many successful scientists when formulating theory look for confirming evidence first ('make it a goer'), then seek to find evidence and arguments against it.
I collaborate in thinking	An important part of scientific thinking is both formal and informal collaboration with others in the sharing of reasoning and ideas. For professional scientists, this collaboration in discussing data and how to interpret it is important in conceptual change. There seems no reason to doubt that it also important for school students.

Dimension of Investigation	Aspects (where relevant)	Analysis
1) Origin of the investigation question in pupil understanding		Original question derived from teachers' conceptions of pupil understanding. Unscheduled experiments originated directly from pupils' understanding
2) Origin of investigation question in learners' and /or teachers' goals.		Originated in teachers' goals, including unscheduled experiments, though these were turned into goal for pupils of proving their theory
3) Control of the investigation.		Teacher set parameters through materials provided, but pupils directed themselves within these.
4) Degree of openness of the investigation		More open than simple hypothesis testing but closed in that resources provided would tend to direct them towards particular answers. Also, experimental test of pupils' theory closed in sense that it could be resolved relatively easily.

5) Aspects of scientific thinking used in the investigation	*Observation*	Supported
	Categorisation	Supported
	Pattern recognition	Supported
	Hypothesis formation and testing.	Supported
	Cause and effect thinking	Supported (more so through pupil experiment)
	Ability to separate and co-ordinate theory and evidence. Not ignoring/recognising the importance of disconfirmatory evidence. Realising one's thinking may be wrong and in need of revision.	Supported (through pupil experiment)
	Visualisation	Supported through models, diagrams etc.
	Making the implicit explicit in one's thinking. Developing control of thinking and representations - metacognition.	Supported
	Ability to use metaphor and analogy	Supported in theory debate
	Use 'confirm early-disconfirm late' heuristic	Not supported
	Collaborative (distributed reasoning)	Supported through group work and theory debate

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A teaching tool for supporting scientific thinking through investigations and other teaching methods.

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S-TEAM Work Package 5.

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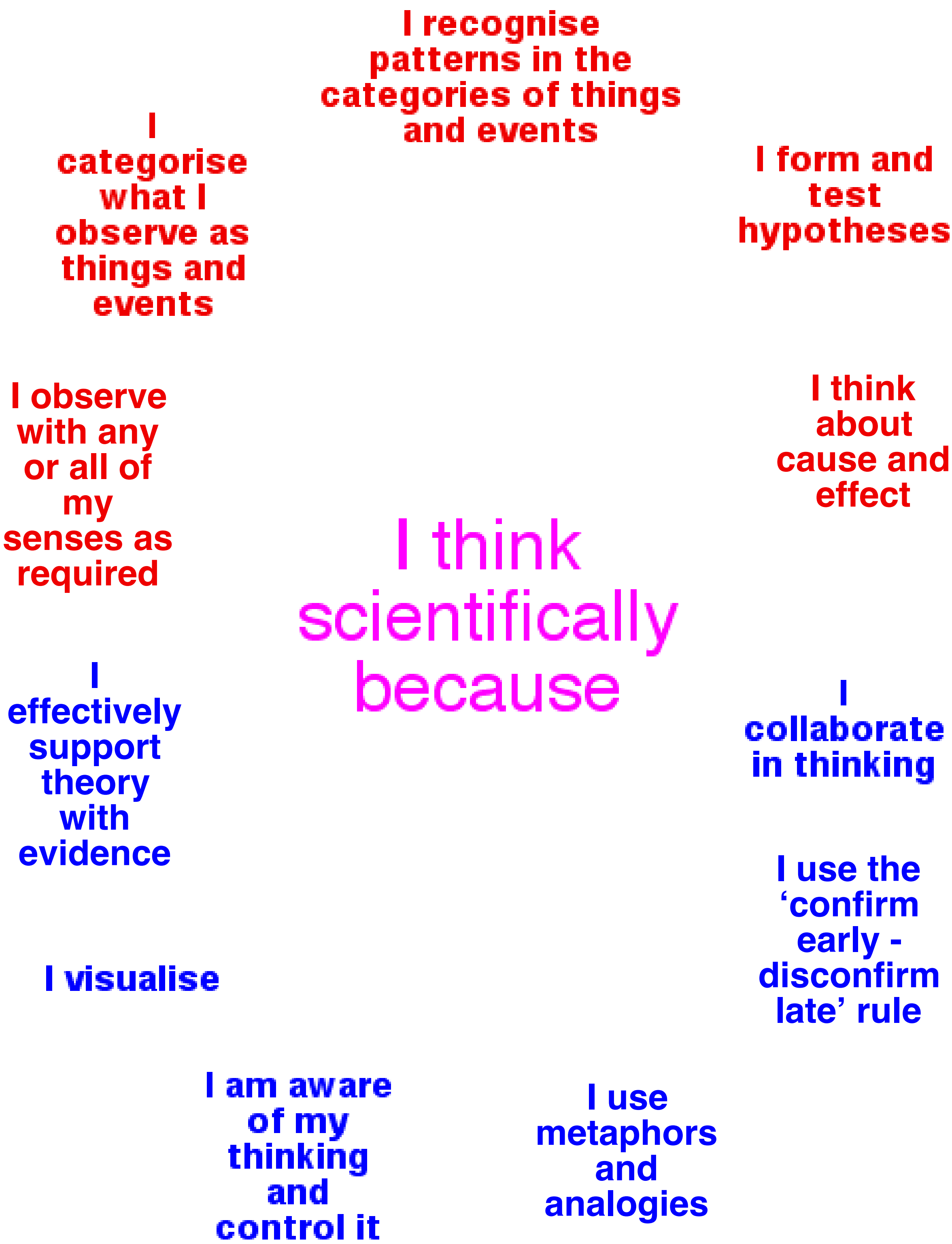
Contents

Figure 1: Scientific thinking tool in visual form



1: Introduction

As teachers, one thing we want to do is to help our pupils to think scientifically. To be successful learners in science and to use this learning confidently, responsibly and effectively as citizens and contributors to society, our young people need to develop and control the mental activities that make up scientific thinking. We have developed a model of scientific thinking to help us all to think about this question – *what aspects of scientific thinking are supported by the different sorts of teaching activities that we use in our classrooms?*

The model of scientific thinking (the diagram on page 1 shows it in visual form) is based around the mental activities that psychology suggests combine (not necessarily all at the same time) to constitute scientific thinking. We call these mental activities *aspects of scientific thinking*. This is because they interact with each other. For example, as we develop scientific theories, we come to observe and categorise the world in different ways. Just think of the change of perspectives you are trying to encourage your pupils to take in many topics – importance of plants, laws of motion, molecular nature of matter, for example. We, therefore, think there is a danger in treating these aspects of scientific thinking as skills that we can practice individually and out of the context of doing meaningful science. However, it is possible to use them to audit our practice for the degrees to which they are supported. Then we can use this information to map out ways of improving on this. This involves placing scientific thinking into a broader model of school science investigations that enables us to think about the teaching decisions we need to make to support this aim. The model is outlined in the next section.

We have tried using this wider model as a tool for analysing various classroom activities, including investigations for formal assessment, common course work experiments and more open investigations conducted by our pupils (see the sections containing examples, below). In all of these, we have been encouraged to find that the activities are potentially supportive of scientific thinking. However, we also find that for our pupils to be able to use this support, we need to find ways to help them to recognise the connection between the activities they are carrying out and scientific thinking. We cannot, even if we wanted to, specify solutions to this problem so that we can tell teachers what to do. It is something that we believe teachers are best placed to solve and, where necessary, resolve with different classes and different activities. However, although we cannot specify solutions, we hope to develop hints and pointers that teachers can use.

The next section presents the whole model of investigations in what we hope is a more accessible and useful form for teachers than in the original academic justification (Smith, 2010).

2: A five-part model of investigations.

As noted above, one part of this wider model of investigations is the model of scientific thinking in Figure 1. The aspects of this model are explained in Tables 1 and 2.

Table 1: Fundamental aspects of scientific thinking

Scientific Thinking **(Adapted from Feist, 2006)**	
Aspect	**What it involves**
I observe with any or all of my senses as required	Fairly self-explanatory – all senses (not just vision) may be used as appropriate to input information
I categorise what I observe as things and events	Classifying information from observations into meaningful concepts or systems of concepts
I recognise patterns in the categories of things and events	Seeing patterns of relationships between different things and events the classified information above refers to (E.g. Thing A is always found with Thing B. Event Y always follows Event X)
I form and test hypotheses	Arises initially from pattern recognition. Begin to expect world to behave in certain ways and test these expectations
I think about cause and effect	Arises initially out of pattern recognition and/or hypothesis verification (e.g. recognition of pattern that Y follows X or verification of this as a hypothesis leads one to think about causes). More sophisticated when one realises that co-variation is necessary, but not sufficient, for causality.

Table 1 can be thought of as containing those aspects of thinking that are found in both everyday and scientific thinking. In young children, and often even in adults, they occur without much awareness. For scientific thinking both language and those aspects in Table 2 enable us to become more aware of it and to take control of its direction more effectively.

We emphasise again that these aspects of scientific thinking may not all be involved in every professional scientific activity and nor should we expect them all in every school science activity. Also, we again emphasise that the aspects interact with each other. For example, as we develop knowledge and understanding of scientific theories, this affects the way that we observe and categorise things and events in the world around us. The model allows us to think about those aspects of scientific thinking that the activities we use in the classroom help our pupils to develop.

We said that this model of scientific thinking is one part of a wider model of school investigations. This wider model, along with some practical questions it raises for teachers, is presented in Table 3. You will see from this model, however, that scientific thinking is a key component that connects the other parts. These other parts of the model are to do with features of the investigations themselves- their origin, degree of teacher/ pupil control and certainty of outcome (openness). Also, we do not assume that the questions in the table are the only ones that could be asked. Teachers should feel free to add others that they feel apply to their own classrooms.

Table 2: Further aspects of scientific thinking	
Scientific Thinking/scientific mind (adapted from Feist, 2006)	
Attribute/skill	**What it involves**
I effectively support theory with evidence	This includes avoiding confirmation bias, not ignoring disconfirmatory evidence outright, avoiding distorted interpretations of evidence to fit preconceptions and distinguishing examples from principles.
I visualise	Visualisation in scientific thinking can take various forms including thought experiments, models and diagrams, graphs, charts and tables. These tables, for example, comprise an attempt in visualising scientific thinking.
I am aware of my thinking and control it	Although beginning in observations, scientific thinking is not sensory bound but can make use of abstract concepts and theories. Scientific thinking involves being aware of these concepts and theories so that they can be challenged and modified. Along with this awareness is also an awareness of the thought processes being used and directing them towards goals such as understanding.
I use metaphor and analogy	Analogy – seeing how something (target) is like something old (source). Metaphor – an 'as if' comparison. Think about X as if it was Y. Both of these are used in scientific thinking in the process of hypothesis and theory formation, thought experiments, creativity and problem solving. In thinking about experiments in one context, we also may use analogies based on experiments from other contexts to design the experiments or to fix problems we are having with it. Analogy and metaphor also provide useful constraints to solutions to problems by focussing strategies
I use the 'confirm early-disconfirm late' heuristic	In practice, this may be rarely used in school science but is included here for completeness. Apparently many successful scientists when formulating theory look for confirming evidence first ('make it a goer'), then seek to find evidence and arguments against it.
I collaborate in thinking	An important part of scientific thinking is both formal and informal collaboration with others in the sharing of reasoning and ideas. For professional scientists, this collaboration in discussing data and how to interpret it is important in conceptual change. There seems no reason to doubt that it also important for school students.

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Table 3: Five dimensions of investigations and some associated teaching questions

Dimension of Investigation	**Some Teaching Questions That Arise**
1) Origin in understanding. That is, does the question behind the investigation derive from pupils' thinking inspired by everyday understandings, or does it derive from pupils' thinking inspired by new scientific understandings they have developed or are developing in the coursework?	a) Can I justify pursuing it within the content requirements of this course? If not, have I got time to pursue it for other reasons (e.g. 1b, 1c and 1d or 2b, b) What are the consequences, such as continued misconceptions, if I leave it? c) Can I justify pursuing it because it is likely to promote engagement? d) What aspects of scientific thinking (dimension 5) would be supported by this investigation?
2) Origin in goals. That is does the question behind the investigation arise from students' and /or teachers' goals?	a) Did I instigate this investigation, or did the pupils, or is it the result of a jointly felt interest? b) Did I instigate this investigation as a challenge to pupils' pre-understandings? c) Did the pupils instigate this investigation out of interest and will it promote engagement? d) What aspects of scientific thinking (dimension 5) would be supported by this investigation?
3) Control of the investigation. That is, who will direct the activity – the students, the teacher or will control be shared in a partnership?	a) Will the pupils be able to devise unaided a suitable investigative strategy, or do we devise it together, or do I suggest the strategy to them? b) Am I controlling the investigation to ensure coverage of course aims and ability by the pupils to deal with assessment requirements? Can I achieve this without exerting this degree of control? c) (Related to 'a' above) What aspects of scientific thinking (dimension 5) do they need to devise and carry out an investigation of this question and when and how do I put scaffolding in place when these aspects are absent or need help in developing? Are some of them only able to be practised when pupils have a certain amount of control?
4) Degree of openness of the investigation That is, how limited is the investigation in either the solutions that the students will come to, and/or in the scope of experimental, observational or text-based (including Internet) research required?	a) Is the investigation question closed enough to be answered quickly and with a reasonable certainty that the pupils will come to scientifically accepted conclusions? b) Is the question too open to be fitted in to the constraints of time and course requirements? c) In open and, possibly also, closed investigations, how will I monitor the development of pupil's understandings and challenge any initial and/or developing alternate or misconceptions? d) What aspects of scientific thinking (dimension 5) are supported by closed and open investigations? Are some of them particular to certain types of investigations?
5) Aspects of scientific thinking used in the investigation	a) What aspects of scientific thinking would be supported by this investigation and do I need to do other types of investigation to ensure all are practised effectively?

Let us also remind you that you cannot expect that every activity, no matter how investigative, will necessarily support pupils in developing all of the aspects of scientific thinking at the same time. Some will be supported by most classroom experiments and investigations, as long as they are set up to answer questions, rather than to be demonstrations of facts. By that we mean that titles such as “To show that….” or “To demonstrate that…” should be avoided, no matter who is doing the experiment (teacher or pupils). Titles such as “To find if/what/how/why…”, and “To look for…” are always better and more likely to lead to forms of activities or interactions between teacher and pupils that support scientific thinking and allow the pupils to make the connections with it. Other aspects of scientific thinking may only rarely be supported in school science investigations, as is suggested in Table 2 for using the ‘confirm early-disconfirm late’ heuristic. However, it may be that teachers will be able to find ways to make support of this and other aspects more common.

3: Examples of analysis of investigations

The following subsections contain examples of our own application of the model of investigations to thinking about some of our own teaching and how supportive it is, at least in principle, of our pupils in developing their scientific thinking. To realise that potential, as we have noted earlier, they may need to be helped in seeing the connection between what they are doing and aspects of scientific thinking. Using the model raises awareness of this, but does not indicate how to solve it. That is something for all of us to work on.

We are not attempting to show wonderful and original practice: just that the model can be applied to a range of activities, some of which you may not judge as truly scientific investigations but rather as artificial attempts to mimic what scientists do. However, we are deliberately avoiding the questions as to whether a particular classroom activity is truly investigative. We are interested, firstly, in the degree to which the activities support scientific thinking. Secondly, can the activities be organised better to support scientific thinking? Thirdly, can the activities form stepping-stones to situations in which our pupils can truly initiate, plan and execute investigations independently of our selves?

The examples that follow begin, deliberately, with the formally required investigations at Standard Grade and Higher Grade levels, then take what might be a common sequence of experiments in biology, then to a closed investigation set by the teacher but in which the pupils have responsibility for finding solutions, and finishing with an investigation in which pupils had the main responsibility for design and implementation. Two of us are, or were, Biology Teachers and so our examples are biological, or have biological elements incorporated. However, even the example provided by Physics teacher among us has a strong biological element deliberately built in. We, therefore, would be happy to receive analyses of investigations from teachers of all science subjects (Physics, Chemistry, more Biology, and general or Integrated Science) to build up a wider range of examples.

Example 1: Analysis of a Standard Grade Investigation[1]

This example is based on the Standard grade Biology investigation, “What might affect the germination of small seeds. With the apparatus (Petri dishes, cotton wool, measuring cylinders, seeds, and so on) in front of them, pupils generally do this investigation quite well in the experience of those authors who are biologists. At least, they do once they have ‘hit upon’ a way of measuring the rate of germination (generally, counting the number of roots that have appeared after a certain time) and providing they have had practice in using the booklet on previous occasions.

[1] An examination taken by Scottish pupils around age 16.

Table 4: Analysis of 'S' Grade Investigation (Germination in small seeds}.		
Dimension of Investigation	**Aspects of scientific thinking)**	**Analysis**
***1) Origin in understanding*.**		Depends, perhaps, on when in the course it is carried out. Germination is in the course, so may be construed as relating to their developing biological understanding. However, if they have not reached germination, they still generally have no problem generating lists of relevant variables from their own understanding.
2) Origin in goals.		Teachers' assessment goals
3) Control of the investigation.		Teacher through assessment booklet and allocation of resources
4) Degree of openness of the investigation		Relatively closed – only a limited number of independent variables can realistically be manipulated in the school laboratory
*5) **Aspects of scientific thinking used in the investigation**.*	*I observe with any or all of my senses as required*	Supported (vision) through examining seeds for signs of germination.
	I categorise what I observe as things and events	Not supported
	I recognise patterns in the categories of things and events	Supported through analysis of graphs
	I form and test hypotheses	Supported through appropriate parts of the booklet
	I think about cause and effect	Supported, at least in terms of choosing how to measure dependent variable which requires a realisation that germination will lead to roots appearing.
	I effectively support theory with evidence	Possibility of need to revise thinking supported if their hypotheses are not in line with results actually obtained.
	I visualise	Supported through graphs
	I am aware of my thinking and control it	Supported through booklet, although has to realise that the booklet is modelling how to carry out investigations of a'fair test' type.
	I use metaphor and analogy	Not supported
	I use the 'confirm early-disconfirm late' heuristic	Not supported
	I collaborate in thinking	Not supported

Perhaps the table suggests that this form of formally assessed investigation is more use than we might suspect and could be justified as one tool in supporting some of the aspects of scientific thinking – most of Table 1 and some of Table 2. Nevertheless, even in accepting this, we should also be aware that an analysis like this, however useful in some respects, might hide issues. For example, as recorded in the table, the booklet can be supportive of metacognition related to how to direct one's thinking through an investigation aimed at hypothesis testing through what might be called a 'fair test procedure', but only if the pupils perceive it as such. If they see it as no more than an assessment booklet to be completed, then that metacognitive support may be lost. There is a duty on us, as teachers to create a context, in which the pupils see the booklet as a support for scientific thinking and for that they need some awareness of scientific thinking, and its aspects, as goals for their learning. Perhaps, as Standard grade fades out, we should not be in too much of a hurry to forget these investigative booklets, but look at ways in which we can use them to work towards the aims of the Curriculum for Excellence through their role in helping us to help our pupils to develop scientific thinking.

Example 2: Analysis of Higher Investigation[2]

For those of you who are not Biologists, transpiration is the evaporation of water from the leaves of plants. This can be measured using a piece of apparatus called a bubble potometer (Figure 2) in a standard series of experiments in which temperature, humidity or air movement can be varied. These experiments form the basis for their Higher Biology Outcome 3 assessment.

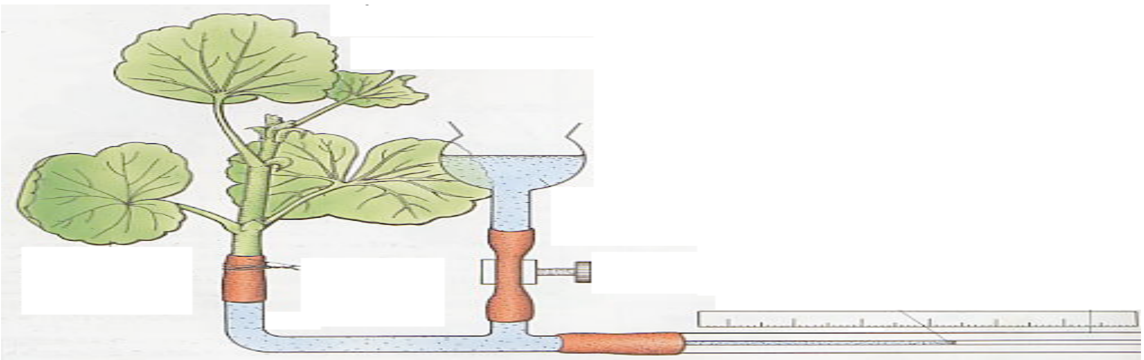


Figure 2: A bubble potometer that can be used to investigate evaporation of water from leaves.

The question they are set is, 'What factors affect the rate of transpiration in plants? The analysis is shown in Table 5. Again, we can see that quite a lot of aspects of scientific thinking are supported. We will return to more general comments later.

[2] An examination taken by Scottish pupils at age 17/18.

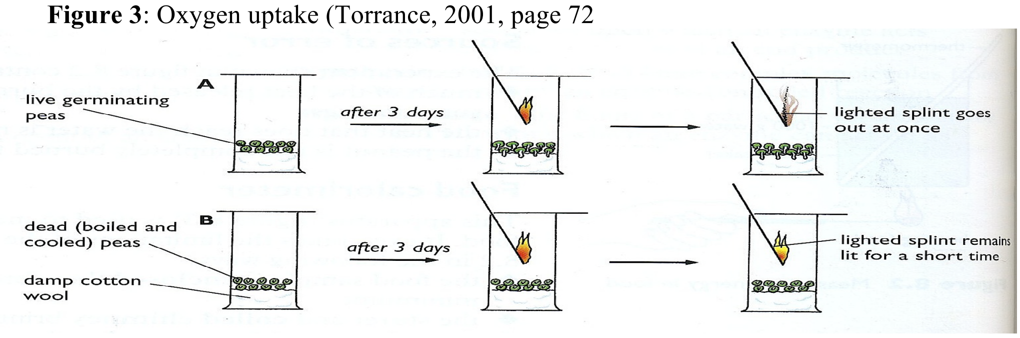
Table 5: Analysis of Higher Investigation (A transpiration investigation using bubble potometer}.		
Dimension of Investigation	**Aspects of scientific thinking)**	**Analysis**
***1) Origin in understanding*.**		Question chosen by teacher from booklet of Higher Biology investigations.
2) Origin in goals.		Instigated by teacher to reinforce content knowledge and understanding, develop investigative skills and meet the assessment criteria.
3) Control of the investigation.		The investigation was controlled by the teacher, through the practical guide to a large extent. Pupils are encouraged to take some control in that they are asked to choose which factor they will investigate and how they will alter that factor.
4) Degree of openness of the investigation		The investigation was very closed. The pupils were limited in their choices and the scope of the investigation was set by the teacher through the practical guide.
***5) Aspects of scientific thinking used in the investigation*.**	*I observe with any or all of my senses as required*	Supported through observation of variables.
	I categorise what I observe as things and events	Not supported – this investigation does not involve categorisation by its nature.
	I recognise patterns in the categories of things and events	Supported – pupils are expected to recognise patterns in the variables.
	I form and test hypotheses	Supported – pupils are asked to predict what impact their variable will have when choosing it.
	I think about cause and effect	Supported – pupils are required to relate the change in their variable to the rate of transpiration.
	I effectively support theory with evidence	Supported – one of the key purposes of the investigation is to test the theory covered in the content.
	I visualise	Supported – pupils represent their results graphically.
	I am aware of my thinking and control it	Supported – pupils are asked to consider the relationship between the evidence from the investigation and the process of transpiration. Through this process they develop their

Table 5: Analysis of Higher Investigation (A transpiration investigation using bubble potometer}.		
Dimension of Investigation	**Aspects of scientific thinking)**	**Analysis**
		thinking.
	I use metaphor and analogy	Not supported – this investigation does not incorporate this aspect.
	I use the 'confirm early-disconfirm late' heuristic	Not supported – as outlined elsewhere, this is not a common aspect in school science. In this case, no effort was made to attempt to 'disconfirm' the theory underpinning transpiration.
	I collaborate in thinking	Not supported – although the pupils carry out the investigation in small groups, due to the high degree of control and the lack of openness this did not involve 'collaborative thinking'.

Example 3: Analysis of respiration experiments

Biology teachers will be familiar with the set of experiments, shown in Figures 3-6, or variations on them, that can be found in Scottish textbooks (e.g. Torrance, 2001) and be presented as testing the validity of the equation for respiration.

Figure 3: Oxygen uptake (Torrance, 2001, page 72



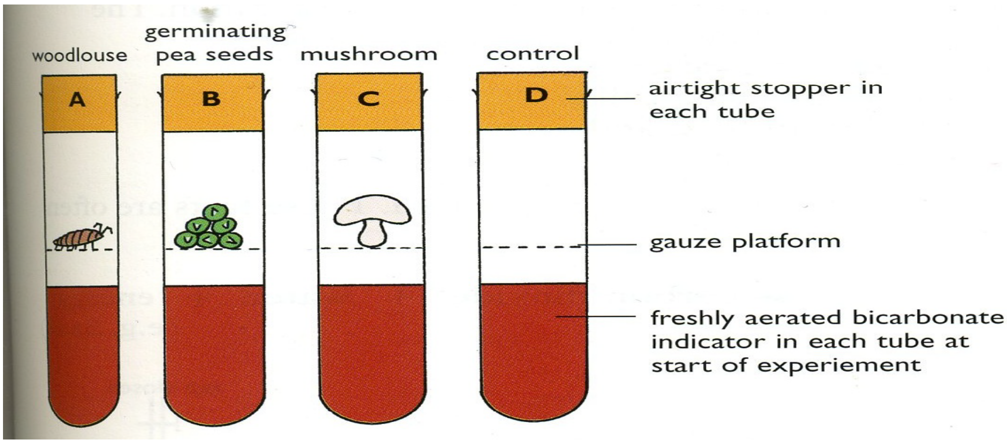


Figure 4: Release of Carbon dioxide in respiration (Torrance, 2001, page 73)

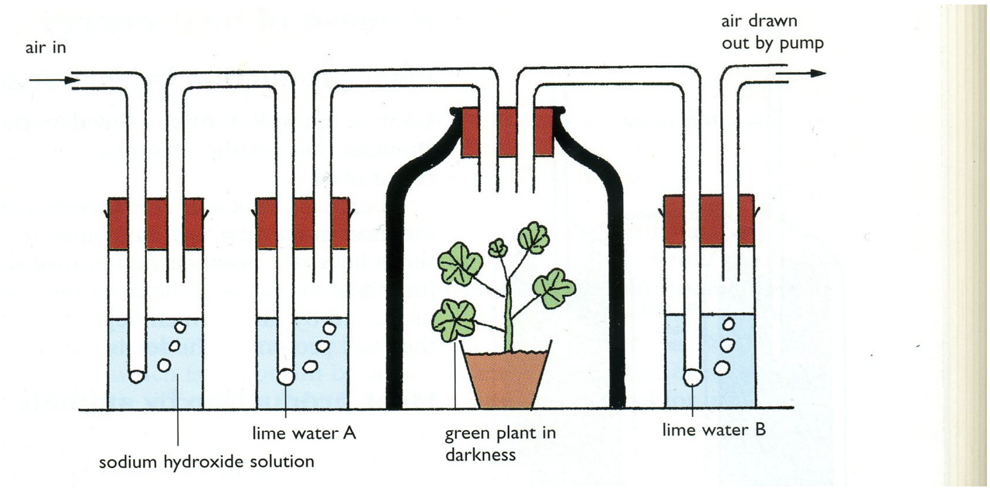


Figure 5: Release of Carbon dioxide by green plants (Torrance, 2001, page 73)

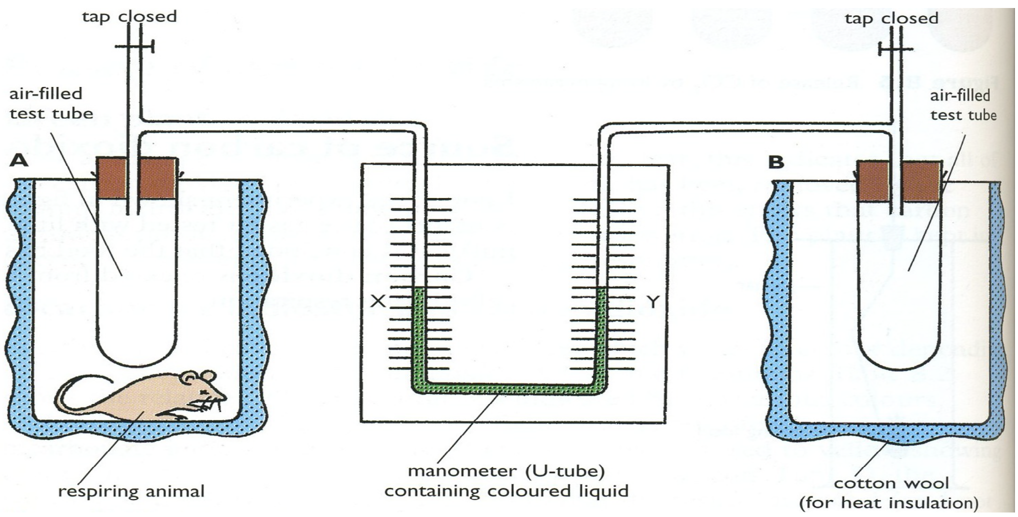


Figure 6: Release of heat by respiring animal (Torrance, 2001, page 74)

In addition to presenting an opportunity for pupils to engage in practical work, understanding these experiments also constituted useful preparation for formal exams in which questions were designed around these or similar forms of experiment. In general, these experiments use a fair test procedure through the use of controls.

In the school in which one of us worked, the departmental approach, rightly or wrongly. was to begin with the analogy (through burning foods and measuring energy released, gases inspired and expired) between burning and respiration to derive the respiration equation and then use these experiments to test the equation. Titles might, therefore, be, 'To find if oxygen is used by germinating seeds for respiration.' and so on, in order to try to introduce some investigative element. It is also worth noting in passing that the thinking in some of the experiments is fairly sophisticated, in that it involves a number of steps. In the experiment in Figure 4, they have to understand that carbon dioxide changes the pH of Bicarbonate Indicator and hence its colour. For that in figure 5, they have to follow the facts that sodium hydroxide absorbs the carbon dioxide from the incoming air, that lime water A container checks that no carbon dioxide is entering the jar with the plant, and, therefore, any carbon dioxide showing in lime water B must have come from the plant. For figure 6, they have to grasp reasoning about heat causing the air in test tube A to expand relative to that in B. So, how does all this come out against the dimensions of investigations (Table 6)?

Again, there is more support for the aspects of scientific thinking than we might assume at first sight. However, as so many of the aspects in this example involve effective support by the teacher, it further highlights our responsibility not merely to follow the experimental pathways in a "we must do this" frame of mind, but to find ways of engaging pupils in ways that enable them to see the connections between the ways they are being encouraged to think and the way that scientists think. Hints emerge for teachers in developing their practice, such as encouraging forms of interaction between oneself and the pupils that promote collaborative thinking. However, in some ways this is encouraging. We do not always need to radically change what we do but just redirect our teaching in ways that enable the pupils to realise that they are being helped to develop their scientific thinking

Table 6: Analysis of series of experiments investigating respiration

Dimension of Investigation	**Aspects of scientific thinking)**	**Analysis**
1) Origin in understanding.		Pupil understanding but guided to issue by teacher
2) Origin in goals.		Teachers goals usually. Teacher would need to find ways of making pupil feel goals were there own
3) Control of the investigation.		Teacher since are following standard experiments, rather than designing them from scratch
4) Degree of openness of the investigation		Closed through the setting up of the experiments to produce results desired
5) ***Aspects of scientific thinking used in the***	*I observe with any or all of my senses as required*	Supported, as pupils have to observe the results of each experiment.

Table 6: Analysis of series of experiments investigating respiration		
Dimension of Investigation	**Aspects of scientific thinking)**	**Analysis**
investigation.	*I categorise what I observe as things and events*	Supported (Plants and animals, for example)
	I recognise patterns in the categories of things and events	Supported, sometimes requiring thinking involving several steps
	I form and test hypotheses	Supported, although guided by the teacher
	I think about cause and effect	Supported, although guided by the teacher
	I effectively support theory with evidence	Ability to co-ordinate theory and evidence, again guided by the teacher and the way the sequence of experiments is set up.
	I visualise	Supported by diagrams
	I am aware of my thinking and control it	Potentially, but probably needs skilful signposting by the teacher.
	I use metaphor and analogy	Supported through analogy with burning.
	I use the 'confirm early-disconfirm late' heuristic	Not supported
	I collaborate in thinking	These experiments tend to be teacher led, so this would depend upon the quality of interaction.

Example 4: Analysis of investigation into factors affecting wind dispersal of seeds.

This investigation is an example in which more control is handed over to the pupils, although it was presented to them as a challenge in which they had to compete to find the most effective design for a wind dispersed seed. It was carried out with pupils in their first year of secondary schooling, who were, therefore, around age twelve. The question being investigated was, 'What are the factors limiting plant seed dispersal by wind?' The pupils worked in teams to produce various designs of model seeds using a marble, newspaper and sellotape in order to get them to travel as far as possible.

Table 7: Testing models of seeds to investigate factors limiting seed dispersal by wind		
Dimension of Investigation	**Aspects of scientific thinking)**	**Analysis**
1) Origin in understanding.		This question arose from experience of teaching this content with pupils. Having found a lack of understanding of the relationships between seed design, dispersal and resource economy, I wanted to devise an inquiry type approach to try to improve this.
2) Origin in goals.		Although the activity was

Table 7: Testing models of seeds to investigate factors limiting seed dispersal by wind		
Dimension of Investigation	**Aspects of scientific thinking)**	**Analysis**
		instigated by the teacher, the competition element encourages goals to be taken over by the learners.
3) Control of the investigation.		There is a large degree of control from the teacher to maintain the focus of the investigation, however pupils have some control as they experiment, test and modify their designs.
4) Degree of openness of the investigation		The activity is deliberately closed to focus on one particular concept.
*5) **Aspects of scientific thinking used in the investigation**.*	*I observe with any or all of my senses as required*	Supported through looking at seeds, creating models and measuring mass and distance.
	I categorise what I observe as things and events	Not supported
	I recognise patterns in the categories of things and events	Supported through comparisons made between shape and mass of models and the distances they travel.
	I form and test hypotheses	Supported through trial and error. Pupils have an initial idea for the most effective solution and modify this repeatedly following testing.
	I think about cause and effect	Supported – pupils must relate the shape and mass of their model with the distance it travels.
	I effectively support theory with evidence	Supported – pupils own theories of the most effective shape are supported, or not, through measurement of distance travelled.
	I visualise	Supported through models and comparison to seeds.
	I am aware of my thinking and control it	Not supported
	I use metaphor and analogy	Supported – the entire exercise is a metaphor as the issues faced by the pupils in their production of their models relates directly to the selection pressures facing plants in seed dispersal.
	I use the 'confirm early-disconfirm late' heuristic	Not supported
	I collaborate in thinking	Supported – the pupils are working in teams and must be able to work collaboratively to arrive at a shared plan of action, and on how best to modify this in light of testing.

with a fan. The weight is taken into account when calculating the winner (score = distance/mass). Table A2.1 shows the analysis using the five dimensional model of investigations.

Example 5: Analysis of Investigation of effect of colour of light on plant growth

This is an example in which the question is again provided by the teacher, but it aims to give them even more control on experimental design than the wind dispersal investigation just described. It was also a deliberate attempt at an investigation that involved more than one science. It was introduced to a science class towards the end of S2 with the aim of answering the question “Does the colour of light affect plant growth?” The question itself arose at a Curriculum for Excellence workshop and was designed to be as open as possible. Pupils were required to design the experiment, select the criteria and build the equipment, the latter with the aim of maintaining engagement among pupils less interested in Biology.

Lightproof cardboard boxes were fitted with light emitting diode (LED) circuits for red, yellow or blue monochromatic illumination (see Figure 7, below). Pupils were required to learn about circuit diagrams, wiring of LEDs and how to solder components onto a stripboard.

Figure 7: Test board showing operation of blue LED lighting circuit.

Pupils agreed as a class that plant height, leaf width and leaf colour would be used as criteria to determine plant health. In the case of width and height, a ruler could be used. For leaf colour, pupils generated colour charts similar to those used in DIY stores to display paint ranges (Figure 8). A progressive sequence of green shades was painted on white paper. When dry, squares were cut out and glued to a piece of card to provide a range of reference colours.

Figure 8 Construction of comparative leaf colour chart.

Additional information available at
http://blog.mrmackenzie.co.uk/2008/04/07/is-there-really-dead-time-in-the-school-year/

Table 8: Analysis of investigation of effect of colour of light on plant growth

Dimension of Investigation	Aspects of scientific thinking)	Analysis
1) Origin in understanding.		This investigation provided an opportunity for engaging practical work related to earlier study of the 5-14 photosynthesis topic and the chance to learn wiring and soldering skills. It was designed to appeal to pupils whether they had expressed a preference for biology or physics in S3 (about age 15).
2) Origin in goals.		The question had been suggested at a Curriculum for Excellence meeting during a discussion on opportunities to bring the three sciences together with practical activities. In whole class discussion, pupils knew the role of sunlight in photosynthesis and could state that sunlight contains all the colours of the spectrum but were unable to suggest which (if any) of these colours were more important for plants to grow.
3) Control of the investigation.		Working in small groups, pupils generated ideas on how to answer the question. All ideas were shared with the class and pupils voted on the best strategy to adopt for the investigation. Occasional questions from the teacher were used to probe for gaps in the project plans produced. Colours of light were limited to red, yellow and blue. This essentially split the class into three teams for all tasks related to the investigation.
4) Degree of openness of the investigation		Investigation was relatively open in that pupils chose their own success criteria and metrology methods for determining the health and growth of plants.
5) Aspects of scientific thinking used in the investigation	*I observe with any or all of my senses as required*	Supported
	I categorise what I observe as things and events	Measurements of plant height, leaf width and leaf colour all used to determine plant health.
	I recognise patterns in the categories of events of things and events	Information obtained from plant observations were plotted to give visual representation of findings. Pupils used these to identify relationships in the data. Pattern recognition was also inherent in the manufacture of the lighting circuits.

Table 8: Analysis of investigation of effect of colour of light on plant growth

Dimension of Investigation	Aspects of scientific thinking)	Analysis
5) ***Aspects of scientific thinking used in the investigation***. *(cont'd)*	*I recognise patterns in the categories of events of things and events*	Pupils soon discovered for themselves that light emitting diodes (LEDs) only operate when connected the correct way round. Similarly, defects, such as overheating or using too much solder, could prevent the circuit from functioning correctly.
	I form and test hypotheses	Supported in plant analysis by prediction of leaf colour (comparison with colour chart), leaf width and plant height for each of the light colours in use. Pupils involved in electronics work were able to design circuit layout and test for equal brightness on all LEDs.
	I think about cause and effect	Through use of colours, height, leaf width and function of electronic circuit, all pupils were able to provide an input into this at their own level.
	I effectively support theory with evidence	This was easier for those working on the electronics tasks as problems with a theory could be spotted and rectified relatively quickly. With plant growth, several weeks of data from each group (red, yellow, blue) were required before pupils could test their hypothesis.
	I visualise	Supported through use of weekly leaf width and plant height line graphs. Also "paint chart" for leaf colour.
	I am aware of my thinking and control it	This was encouraged through group updates to teacher on findings each week and discussions on the causes on week-on-week changes. For electronics tasks, discussions around problems encountered and strategies adopted to obtain the required functionality, sharing of soldering advice, best way to clean soldering iron tips, etc.
	I use metaphor and analogy	Unsupported
	I use the 'confirm early-disconfirm late' heuristic	Unsupported
	I collaborate in thinking	See metacognition entry above. Weekly reviews with each groups to discuss findings of plant health, comparison to other group data. Soldering "masterclasses" where pupils share their solution to a common issue.

Perhaps due to its more open nature this investigation raised some interesting issues. First, all pupils were convinced by a point put forward by one of their peers that the investigation would only be "fair" if the lights inside the box were turned off at night. The general feeling in the class was that plants in an outdoor location do not receive sunlight 24/7 and any deviation from a "natural" situation would produce an invalid result. To accommodate this viewpoint, a timer switch was fitted to the power socket providing electricity to the low voltage supply used to feed all three lighting circuits. Pupils decided to switch the lights on at 7am and switch them off at 7pm and set the timer accordingly. While this clearly demonstrates the pupils' sense of ownership, it also indicates the role of knowledge in investigations. More advanced knowledge of photosynthesis enables us to know that it has two stages – one of which is light dependent and one of which is not. Also, that the products of the light dependent stage accumulate faster than the non-light dependent stage can use them, with the result that the latter continues after day light to use them up. We might suspect that constant daylight would not really be an issue. However, have we enough knowledge to be sure? Can the plant cope indefinitely with an excess of the products from the light dependent stage of photosynthesis? Faced with this uncertainty, the pupils, with less knowledge than ours, may have designed the best procedure in this case, but in others could the lack of knowledge be counter productive?

The second point relates to the selection of criteria to determine whether or not plant growth had taken place since the previous observation. Pupils used "everyday" knowledge to explain that one symptom of a houseplant failing to thrive is yellowing of the leaves. They had real world evidence for looking at leaf colour, despite the measurement difficulties that it may entail in the classroom. Of the other indicators chosen, there was agreement on plant height but a 50/50 split between "leaf width" and "distance between leaf shoots on the main stem." Supporters of "leaf width" persuaded their classmates to switch sides and so the former metric was chosen as the third response measurement. I did not influence their choice and without the necessary botanical knowledge I can say only that I *think* the latter option may have been a better indicator for their investigation.

Again, the utility of background knowledge on both the part of the teacher and the pupils is highlighted. This is discussed further in the next section.

4: Comments/ discussion

In all of these examples, we tended to be (pleasantly) surprised at the number of aspects of scientific thinking that were supported. However, looking across them, the crucial factor that seems to be missing is that pupils did not instigate the investigations, and this may make support for scientific thinking less effective, even though the potential is clearly there. However, it is probably unrealistic to expect that we will always be able to allow pupils to instigate every investigative activity, or even a majority of them. This places upon us a responsibility to find ways to help our pupils to make the connections between the activities we engage them in and scientific thinking. However, some of the examples given suggest that this is possible, even in activities that are more traditional such as investigation assessments and traditional sequences of experiments, such as those for respiration. This may require us to highlight even more the support that the assessment format gives for certain aspects of scientific thinking. It may also require us to think how better to encourage forms of interaction between oneself and the pupils that promote collaborative thinking, or at least to do this more consistently in the face of other demands, such as just getting the material covered. However, that is, perhaps, a more optimistic viewpoint than one demanding a radical change of practice that has to be applied at all times.

However, the examples also suggest that there are learning opportunities for our pupils and ourselves when we do move to more open investigations. For ourselves, as example 5 indicates, one of these is opening up our own knowledge to scrutiny. In this case, a little extra knowledge leads to a form of ignorance the pupils, with their everyday knowledge, did not have to face. To them, setting up conditions that mimic reality as close as possible seemed the logical thing to do. We, even in reflection now and without further research, are not sure if this was necessary but have to admit it is the safer thing to do. However, it may not be that pupils' knowledge will always work beneficially in this way, and we need to be aware of this possibility.

For example, pupil misconceptions may also be a problem. Smith (2010) gives an instance of this. A class of second year pupils was exploring and developing their knowledge and understanding of how the eye works. One group introduced a (wrong) theory (in vision, light comes out of the eyes so that we can see) and which spread almost like a virus through the other pupils and had to be dealt with through challenging them to provide experimental evidence that would convince their teachers (Smith and a Support for Learning teacher) that it was better than the one that they and the resources -including videos- they were working with were suggesting (light reflects off objects into the eyes). They did come up with an experiment themselves and found their theory could not cope with the results but this depended on the challenge from the teachers. They did not think themselves that the theory needed testing and even seemed to miss their theory's contradictions with things they had learned and recorded through their research – the lens focuses light on the retina, for example. In fact, in this lies another lesson. The teachers probably would not have noticed the misconception in a more teacher led environment.

Smith (2010) also discusses another- this time hypothetical topic of investigation- that also raises issues about the relationships between both teachers' and pupils' prior knowledge and investigations. In a dinner debate about investigations, the example was raised of what would you do if you were asked by your pupils, "What grows faster, a tulip or a daffodil?"

Perhaps, because of the ‘ambience,’ this seemed a fairly straightforward investigation of a ‘fair test’ type. We can all imagine the sort of experiments we could set up if we had a number of daffodil and tulip bulbs. The only problems would be waiting for the results and, as with the colour of light and leaves example, getting the pupils to agree a measure of rate of growth. However, a little more knowledge of daffodils and tulips suggests that those results would not mean very much. Even a rudimentary search of gardening websites reveals that there are sufficient varieties of both daffodils and tulips, so that examples of both can be found that flower as early as February and as late as May. The results may depend more on which varieties you happen to have, rather than whether it is a daffodil or a tulip. Of course, we can imagine changing our original question –for example, do the bulbs all start at the same time (in the Autumn, when planting is recommended), but the earlier flowering then growing faster? The point is that how much knowledge, or how much research you do, as a teacher prior to letting the pupils loose on the investigation may determine the form you guide it towards. Then you may still decide it is worth letting them do their investigation, even though the results will not mean very much scientifically because, since they are pursuing their own question, it ensures their engagement and allows them to practice scientific thinking.

All of the discussion in this section suggests that the first four dimensions and the teaching questions they raise (as shown in Table 3) are important, and that answers to them cannot be prescribed. In our own contexts, as we try to do investigative activities of any kind, we have to carefully consider our pupils’ existing and developing understanding, including misconceptions, and judge how to act as teachers in the light of this. We also have to consider our own knowledge and understanding of the topic in relations to the way the pupils investigate and understand it and again make judgements about how to act. There is a balance, at times at least, between investigations that provide meaningfully scientific results as well as support scientific thinking development in our pupils and those that ensure pupil engagement and support for scientific thinking, but in which the results may not mean very much. Teachers are best placed to make these judgements.

5: Now try it yourselves

So, now we invite you to try the model out for yourselves on examples from your own practice. A blank table is supplied for your use at the end of this document, but feel free to create an electronic version for yourselves. We would welcome examples from you and these can be sent to Colin Smith by email at colin.a.smith@btinternet.com or Peter Gray (S-TEAM project manager at <graypb@gmail.com>

References

Feist, G.J. (2006) *The Psychology of Science and the Origins of the Scientific Mind*. New Haven: Yale University Press.

Smith, C.A. (2010) (With additional material supplied by Kelly, F and Mackenzie, S). Thinking pedagogically about scientific thinking: Towards a taxonomy of investigations**.** S-TEAM Conference, Nottingham. January, 2010. Available at https://www.ntnu.no/wiki/pages/viewpageattachments.action?pageId=8324914&highlight=Thinking+pedagogical3210.doc#What+is+Inquiry-based+science+teaching+%3F-attachment-Thinking+pedagogical3210.doc

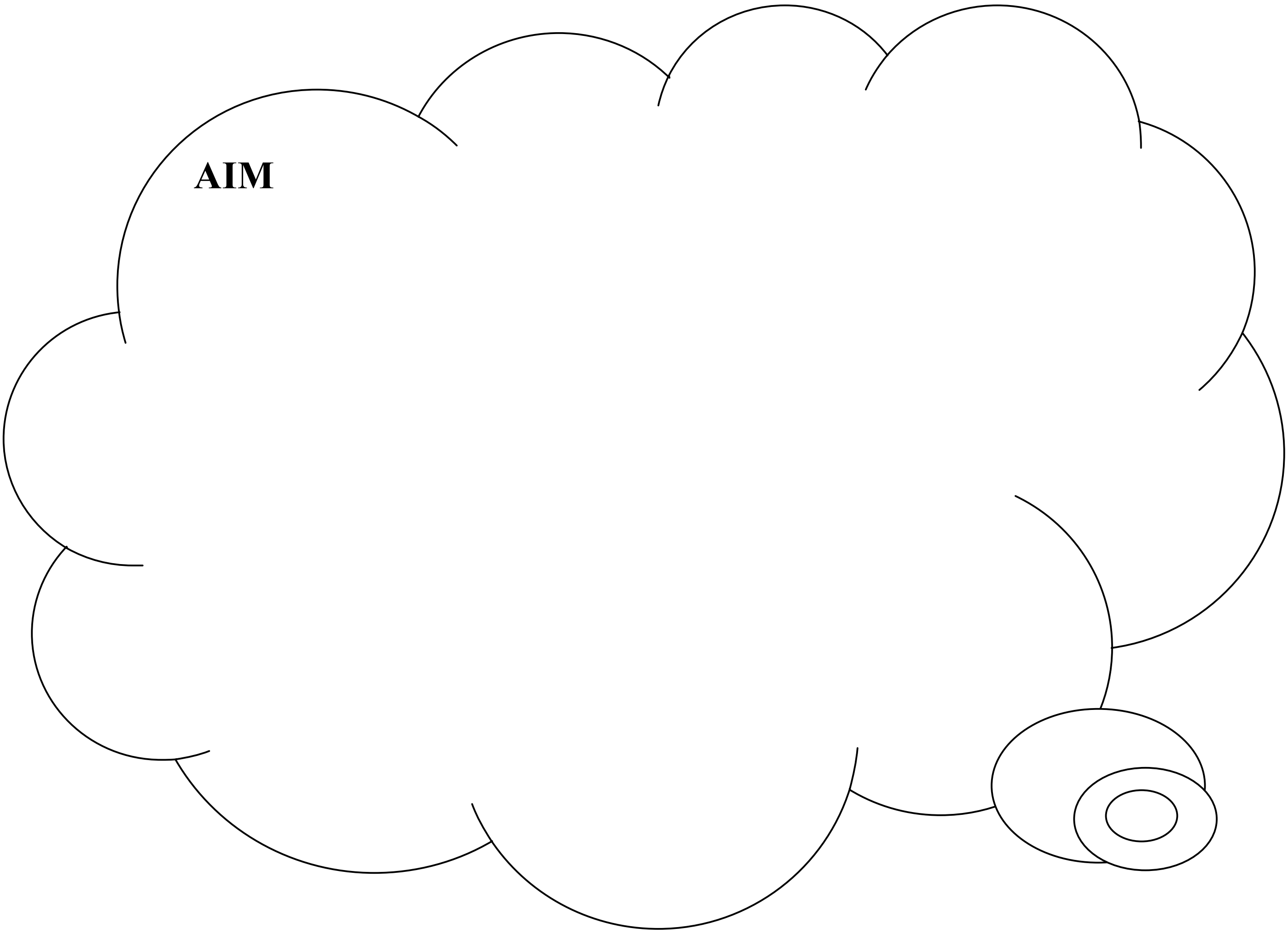
Torrance, J. (2001) *Standard Grade Biology* (3rd Edition). London: Hodder and Stoughton

Dimension of Investigation	Aspects of scientific thinking)	Analysis
***1) Origin in understanding*.**		
2) Origin in goals.		
3) Control of the investigation.		
4) Degree of openness of the investigation		
5) ***Aspects of scientific thinking used in the investigation***.	*I observe with any or all of my senses as required*	
	I categorise what I observe as things and events	
	I recognise patterns in the categories of things and events	
	I form and test hypotheses	
	I think about cause and effect	
	I effectively support theory with evidence	
	I visualise	
	I am aware of my thinking and control it	.
	I use metaphor and analogy	
	I use the 'confirm early-disconfirm late' heuristic	
	I collaborate in thinking	.

Appendix 5

Materials used in Session 3

- Towards intervention questions PowerPoint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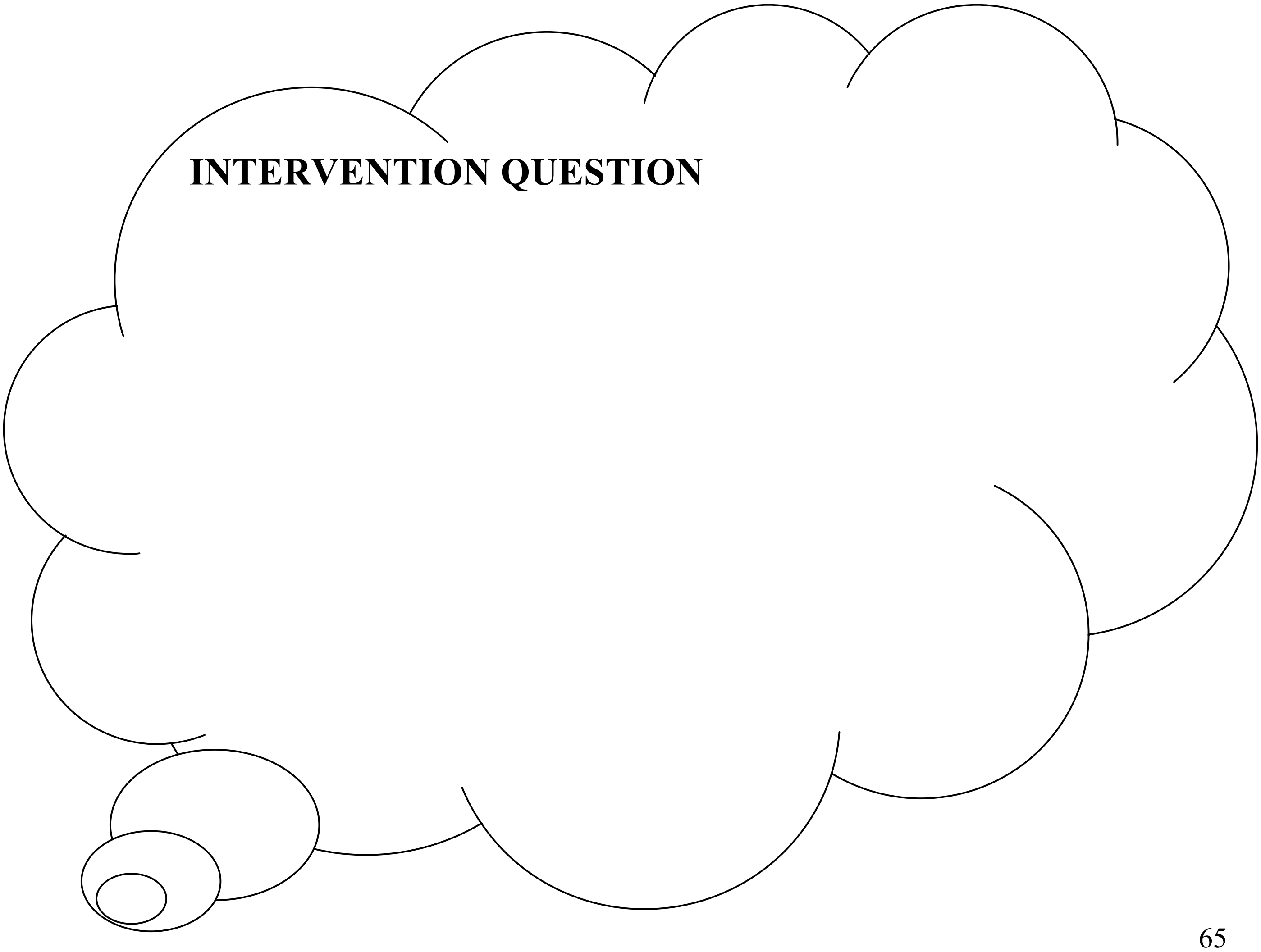
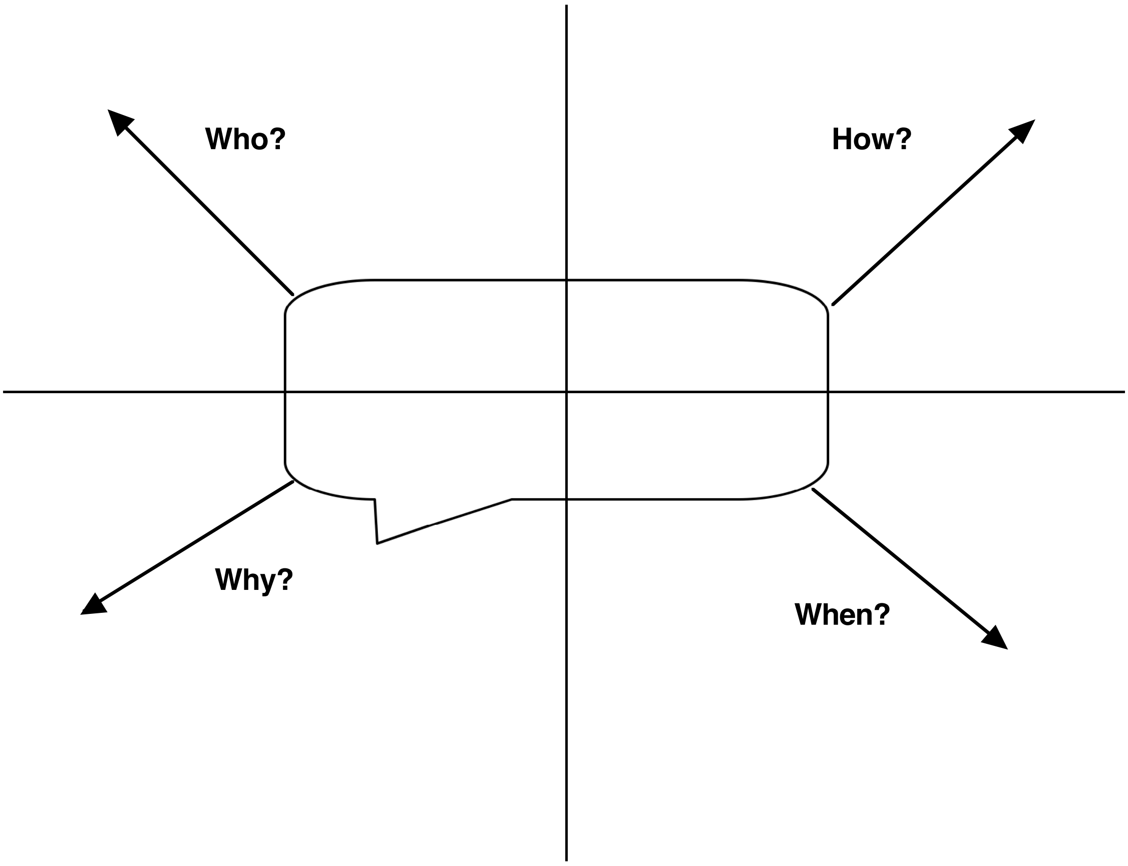
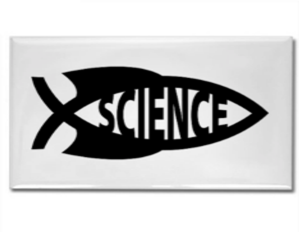

INTERVENTION QUESTION


Who?
How?
Why?
When?

S-TEAM
FIRING UP SCIENCE EDUCATION

Pisces



Towards intervention questions.
Colin Smith

East Lothian Council

University of Strathclyde Education

Different types of intervention questions

For example:

1) What benefits will the pupils get if…..?

Or

2) How do I……..?

Either of these (or other forms) may be appropriate at different times or in different contexts.

Ultimately you have to choose, but I'm going to argue for a form of 2.

Living Theories - Whitehead

- Theories practitioners develop in their own contexts.
- Centre around values - the values the practitioners believe derive from the best interests of their pupils, from the best interests of society, from the subject they teach, and so on.
- I would argue that working through these values (and conflicts between them) is an important part of being a professional practitioner.

The experience of contradiction

Example expressed here in week 1

- I would love to teach this way (by inquiry) all the time.
- But, we have a thing called the SQA and…

Whitehead calls this *experiencing oneself as a living contradiction.*

There is an awareness of a belief in certain values and a negation of those values by what you are doing in practice.

Living theory questions

- Whitehead’s original formulation. These are questions of the general form, *“How do I improve my practice?”* or *“How do I improve what I am doing?”*
- Also, a form of question commonly found in action research.
- Criticised by some, I think rightly, as implying that practitioners’ practice is always inadequate, needs improving, is not successful (by some measures, at least).
- But-

A meaning for ‘improve’?

- What I think Whitehead means, or should mean.
- My practice has improved (from my perspective) when I have worked towards and succeeded in reducing the *experience of living a contradiction.*
- You *‘live the contradiction’* and *‘you live the improvement’.*

Therefore?

- My practice is more in line with the values that I believe are important in this context?

And/or

- I have found a way of working that reduces the conflict between values from different sources (personal, social, curricular, etc.).

Practitioner perspective

- What teaching goals/ methods/ relationships with pupils/ outcomes do I value? Perhaps, at the moment you are reappraising this because of the CfE.
- What am I doing that contradicts those values or does not support them?
- How do I work to resolve this discrepancy?

Example 1

- Based on Whitehead.
- A teacher has a belief in learning by inquiry.
- Negated by mainly using transmission methods.
- How do I reduce my reliance on transmission methods and facilitate more inquiry by my pupils? OR
- How do I support my pupils in engaging in and learning through inquiry?

Example 2
From Brownlie et al, 2008

- Belief that pupils should be able to find information, not commit plagiarism and the information should be understood.
- Pupils commit plagiarism by pasting in unacknowledged text and download university level material they cannot possibly understand.
- Believe that pupils do this, in part at least, because of our teaching methods and our classroom ethos.

Intervention question

- How do we support our pupils in developing their information skills?

Preferred above to more technological formulations below (do you agree?)

- How do we improve the information skills of our pupils?

Or

- How do we become better at improving the information skills of our pupils?

Initial question might need focussing

- How do we support our pupils in developing their information skills?

Became

- What intervention can we design that supports our pupils in finding information relevant to a learning activity, collating that information in line with the activity and presenting that information in the form required by the activity, but avoiding plagiarism?

Examples (less esoteric?) from Whitehead's website

- *Marian Lothian(2010) How can I improve my practice to enhance the teaching of literacy?*
- *Chris Jones (2009) How do I improve my practice as an inclusion officer working in a children's service?*
- *Paul Robert (2003)- Emerging Selves in Practice: How do I and others create my practice and how does my practice shape me and influence others?*

In practical terms?

'How do I improve this process of education here?'.

- *I experience problems when my educational values are negated in my practice.*
- *I imagine ways of overcoming my problems.*
- *I act on a chosen solution.*

This form of enquiry falls within the tradition of action research. It can be distinguished from other approaches in the tradition through its inclusion of 'I' as a living contradiction within the presentation of a claim to educational knowledge.
(Whitehead, 1989)

Possible starters for PISCES

- How do I support my pupils in developing their scientific thinking?
- How do I make my teaching more inquiry-based?
- How do I teach (name of topic) using inquiry methods while ensuring that pupils' understandings are scientifically acceptable?
- And so on.

What do we hope we have given you so far?

- Tools that may help you to conceptualise the problems/issues/directions you wish to take.
- Time to try those tools and think about some of the insights they provide.
- A way of thinking about intervention questions that is empowering to you as professionally minded practitioners.

Next

The opportunity:

- to formulate your own intervention questions,
- to explore them conceptually and in your practice,
- to evaluate the outcomes of this exploration.

References

Brownlie, S., Curran, M., Falconer, L, McAllister, J. and Smith, C (2008). *Supporting our pupils in developing their information skills: How do we do it?* Caldervale High School, Airdrie/ Learning and Teaching Scotland. Available at http://www.ltscotland.org.uk/sharingpractice/c/supportinginformationliteracydevelopment/introduction.asp?strReferringChannel=sharedsharingpractice

This site also has some examples of the materials used. Alternatively a full set of the materials and a copy of the report can be obtained on CD Rom on request from profdevgroup@caldervale.n-lanark.sch.uk

Whitehead, J. (1989) Creating A Living Educational Theory From Questions Of The Kind, 'How Do I Improve My Practice?' *Cambridge Journal of Education*,19(1),1989, 41-52 Also available at http://www.actionresearch.net/writings/livtheory.html

Since you probably have limited access to academic libraries, this site is probably the most accessible way to find out more about Whitehead. Personally and, perhaps oddly, I find this (and other) academic papers more accessible than some of his other writings on this site. There are important insights though, if you are prepared to look for them.