S-TEAM

WP 8 Report

Scientific Literacy and Teacher Professional Development

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Deliverable 8a

Report

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Preface

This report is a revised version of the preliminary report on scientific literacy submitted in M12. It does not claim to provide a comprehensive state of the art analysis of scientific literacy teaching across Europe, which is beyond the scope of this project. It does, however, suggest new and innovative ways forward in the use of Scientific Literacy as a tool for the development of inquiry-based teaching methods, and has resulted in the 'Scientific Thinking' paper (Smith et al, 2010, appended). This paper has been influential within the S-TEAM project and beyond.

The approaches described in this document were used in a successful pilot workshop during the S-TEAM mid-project conference in Glasgow (13-16 October, 2010) and we are now exploring ways of taking this approach forward in the S-TEAM partner countries.

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Introduction

National statements of Scientific Literacy can be found amongst the education goals and objectives for most EU countries. In general their purpose is to give guidance to the direction of science education so that it is responsive to the educational, social and cultural needs of each state. However, from our experience, a large number of teachers in each country are either unaware of the existence of these statements or naïve about their contents and relevance to their teaching. While working intensively with the Scientific Literacy statements of seven countries in the European area, we have examined the potential usefulness of these statements for improving science education through Teacher Professional Development (TPD) programs that use them in meaningful ways.

We have found that a deep working knowledge of Scientific Literacy objectives in both a teacher's own country and for other EU area countries can lead to enhanced opportunities for science teaching, including the use of inquiry. We suggest that each of the following uses of Scientific Literacy statements in TPD has meaningful potential to increase the effectiveness of science teaching. That increase will in turn increase the success of students in reaching the Scientific Literacy goals.

Teacher Awareness

For goals of Scientific Literacy to have any effect on teaching and learning, they must be known, and their potential understood, by both pre- and in-service science teachers. Part of the general lack of close understanding of national Scientific Literacy goals is due to the fact that many in-service teachers began teaching before current goals were established. For new teachers, some current teacher education programs do little more than mention or refer to the goals in passing. The last few decades have seen a change in focus of science education from training future scientists to providing future citizens with Scientific Literacy tools. Teachers do not always possess the knowledge and skills necessary to provide students with these tools. Furthermore many of the notions included in today's statements of Scientific Literacy include values that come from the social sciences, knowledge of which some science teachers lack. A pedagogical challenge lies in not only acquainting teachers with current goals but also giving them a deeper understanding of the relationships within the goals and their potential to inform their teaching.

The format of most goal statements, as abstract text, makes any real understanding of their nature and potential difficult.

Consequently, the Mind The Gap project began a re-representation of national goals in the form of ‘concept maps’ which use mathematical algorithms to visually display textual goals with circles, arrows, colours and varying widths of connecting lines to more accurately reveal the emphases, connections and breadth of national goal statements. The project also developed a workshop, which uses these concept maps to immerse teachers in reflections about scientific literacy as seen from their country’s perspective and how that understanding can be used to change classroom lessons. Figure 1 shows an example of one such map from Denmark. In this instance, the blue highlighted text is read as ‘A student can put into perspective a scientific subject’s contributions to societal and technological development through examples.’ In addition, the map reveals through arrow links that other statements in the document also target societally relevant learning. The colour coding further ads to the clarity of the statement by allowing a teacher to, for example, find all of the action words of the statement coloured with green. Furthermore they can quickly see that the largest green circle is for ‘carry out’, so that the resulting practical work is clearly an important Scientific Literacy goal for students.

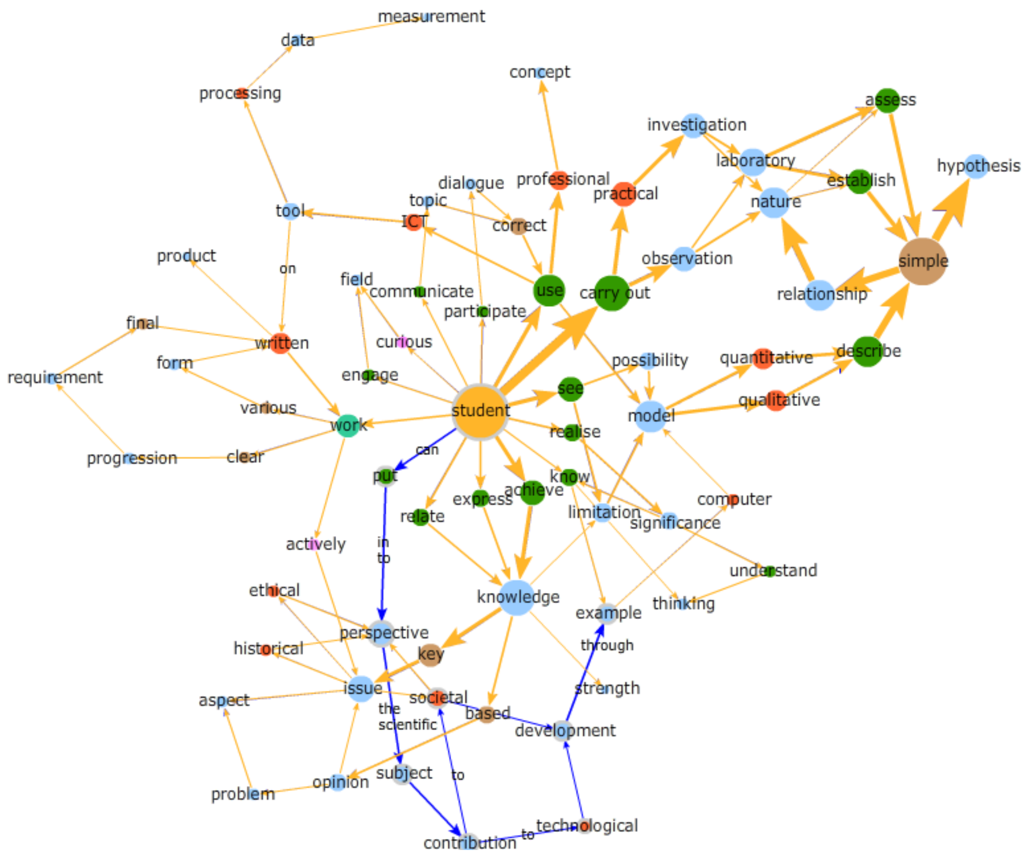

Figure 1. The text of Danish Scientific Literacy is represented in this concept map. For clarity, the path of each sentence from the original text is highlighted in blue when a cursor is moved over it.

The increased awareness which comes from working with the accessibility of maps of Scientific Literacy is the first step in developing teaching methods which are best suited to these definitions but also in turn are more likely to achieve national Scientific Literacy goals.

Promotion of a Renewed 'Need' for New Methods

Many national maps of Scientific Literacy reveal clusters of objectives, which virtually require teaching through inquiry. For examples, see maps at this URL (http://www1.ind.ku.dk/mtg/wp3/scientificliteracy/maps).

Such strong calls for inquiry activity are bound to have an effect on teacher's mental images of their student's abilities and needs, and consequently on their choice of teaching methods of instruction. When such needs for inquiry-based methods are created by deep exposure to Scientific Literacy, opportunities for helping teachers learn to use such methods are enhanced.

Promotion of Inquiry Based Science Teaching

Quite directly, many national Scientific Literacy statements promote teaching science via inquiry methods since such process statements for conducting science are often included. For example, in Denmark's literacy map, the statements connected to 'carry out' require investigative inquiry in laboratory type settings (see Figure 2).

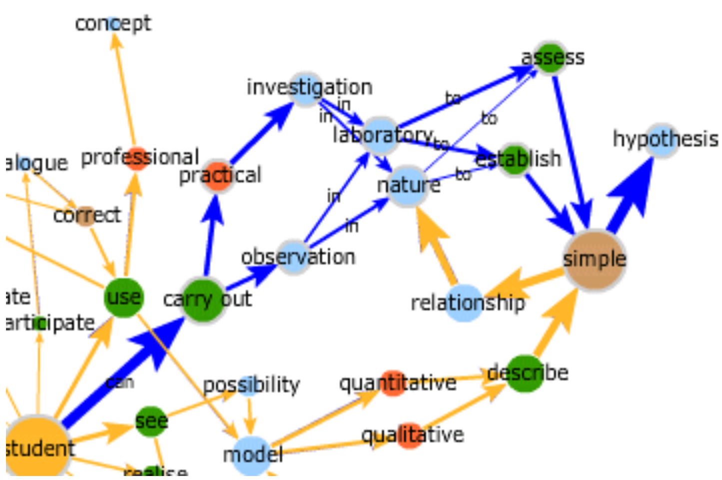

Figure 2. Detail from the Danish map of Scientific Literacy with the student goals associated with 'carry out' highlighted in blue.

When teachers are introduced not only to the text of these inquiry oriented objectives but also to the scientific and pedagogical meanings supporting them, they are better prepared to teach science as it is known to scientists. Teacher education, which includes the concepts behind scientific knowledge, such as the Nature of Science, allows teachers to better understand the inquiry based nature of the scientific enterprise and then to pass that on to students using inquiry based methods. The reason this orientation is often necessary is that many teachers have had limited experience doing research and hence little experience with inquiry. They often have proceeded directly from their first academic degree in a content area to post graduate certification in education, without much exposure to scientific research environments. Furthermore, since most of their university science courses were taught via transmissive lectures and confirmatory laboratories, they have not had many mentors for teaching using inquiry methods.

Colin Smith, Fearghal Kelly and Sinclair Mackenzie have transformed a look at the deeper basis of scientific inquiry by Feist (2006) into a paper (Smith, C., Kelly, F. & Mackenzie, S., 2010: reprinted in this document) addressed to science teachers, which summarizes the bases of scientific thinking and their implications for learners. This summary, seen below in Table 1, clarifies the educational needs for scientifically literate students, all of which can best be achieved through inquiry teaching methods.

Table 1. Aspects of scientific thinking (scientific inquiry) and what each includes from Smith et al. (2010), based on Feist, 2006.

Scientific Thinking (Adapted from Feist, 2006)	
Aspect of Scientific Thinking (AST)	**What it involves**
1 *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
2 *I categorise what I observe as things and events*	Classifying information from observations into meaningful concepts or systems of concepts
3 *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)
4 *I form and test hypotheses*	Arises initially from pattern recognition. Begin to expect world to behave in certain ways and test these expectations
5 *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.
6 *I effectively support theory with evidence*	This includes avoiding confirmation bias, not

Scientific Thinking (Adapted from Feist, 2006)	
Aspect of Scientific Thinking (AST)	**What it involves**
	ignoring disconfirmatory evidence outright, avoiding distorted interpretations of evidence to fit preconceptions and distinguishing examples from principles.
7 *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.
8 *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.
9 *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 focusing strategies
10 *I use the 'confirm early-disconfirm late' heuristic*	In practice, this may be rarely used in school

Scientific Thinking (Adapted from Feist, 2006)	
Aspect of Scientific Thinking (AST)	**What it involves**
	science but is included here for completeness. Apparently many successful scientists when formulating theory look for confirming evidence first ('make it a goer'), then try to find evidence and arguments against it.
11 *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.

To discover the relevance of documents like this to understanding the goals of national Scientific Literacy objectives, it is useful to look at a number of such statements to see how given national demands can be better understood through the Smith et al. (2010) overview. Situating specific national Scientific Literacy objectives in such a larger frame would be useful in working towards Teacher Professional Development since when teachers can see the 'bigger picture' of their national goals, they can better fashion lessons to meet them. Below, we suggest examples of connections between national Scientific Literacy statements and the framework suggested by Smith, et al. (2010) which would be useful in Teacher Professional Development. The maps are best viewed at:

http://www1.ind.ku.dk/mtg/wp3/scientificliteracy/maps.

Denmark's Scientific Literacy Connections to Scientific and Inquiry Thinking

The Danish statement "Student can establish simple hypothesis" covers 'Fundamental Aspects of Science Thinking' (FAST) in Smith et al. (2010) and the aspect 'I effectively support theory with evidence' (AST6). The FAST can be related to this objective because the statement contains observation and the establishment of a hypothesis. The fact that this statement makes hypotheses based on empirical work means that this statement also covers AST6.

The aspect “I am aware of my thinking and control it” (AST8) is related to the following statements: “Student can assess simple hypothesis”, “Student realize significance of knowing limitation of science thinking” and “Students can see possibilities and limitation of model”. The statements related to the node ‘model’ contain the aspect ‘I visualise” (AST7) since model is a part of this aspect. The Danish map also covers the aspect “I collaborate in thinking” (AST11) with the statements that highlights when you mouse over the nodes ‘communicate’ and ‘participate’.

UK/Wales’s Scientific Literacy Connections to Scientific Thinking through Inquiry

The evidence node in the UK/Wales map contains the statement “Student understands how creative interpretation of data provide evidence to test scientific ideas and to develop theory”. This call is only partial, since the students should only ‘understand’ and not ‘conduct’ but it is at least a reflection on AST6. Together with the statement “Student can … collect first-hand data” the student activity is secured and these two statements together effectively cover AST6.

The statement “Student can consider the validity and reliability of method to collect data” is related to AST8 because these considerations give an awareness of the use of concepts and theories and an awareness of how and when to challenge and change concepts and theories.

The aspect about visualising (AST7) is very clear in the UK/Wales map. The statement “Student can use model and theory to develop explanation of many phenomenon” covers a part of various forms of visualising. Also the ‘symbol’ node adds technical, scientific and mathematical symbols to forms of visualising.

The map doesn’t have a hypothesis node, but the statement “Student can plan to test scientific idea and to answer scientific questions” is very much related to the aspect “I form and test hypothesis” (AST4) and to the aspect “I think about cause and effect” (AST5).

Even though the most fundamental aspects of science thinking (AST1-3) aren’t represented directly in the map, they are a prerequisite for some of the other aspects covered in by the map (e.g. AST4 and AST5). AST9-11 are not represented by any statements or nodes in the UK/Wales map of Scientific Literacy.

Scotland's Literacy Connections to Scientific Thinking through Inquiry

The statement "Students can demonstrate honesty in collecting and presenting information/data." and the statement "… consideration of limitations of data." matches well with AST8. The former statement "Student demonstrate honesty in collecting and presenting information/data" also covers AST 6 and perhaps AST 11 if 'honesty' can be understood as a honesty based on reflections on the scientific methods used and not only a (naïve) attitude. AST 11 could also be related to the statement "Student debates and discusses ideas".

The Scottish map doesn't cover Fundamental Aspects of Science Thinking' (FAST) in Smith, et al. (2010), however, as mentioned in the analysis of the UK/Wales map, it is difficult to realize e.g. AST 6 and AST 8 without realizing FAST. AST7, AST9 and AST10 are not represented in the Scottish map.

Israel's Literacy Connections to Scientific Thinking through Inquiry

The Israeli map doesn't explicitly include statements or nodes about empirical work which makes it more difficult to relate to the aspects of science thinking. It is possible to recognise AST3 in the statement containing the patterns node as well as the statement "… logical argument" covers AST5. However, the statement "Students cope with problems include…" could very well contain empirical work training students in scientific thinking and competencies. If so, at least the FAST would be covered by the map. The statement "Student has attitudes…" could include some of the reflections represented in AST6 and AST8. The Israeli literacy statement doesn't address AST7 and AST9-11.

Hungary's Literacy Connections to Scientific Thinking through Inquiry[1]

The statement "Students can build up science related approach and way of thinking." is relevant in principle to most aspects of scientific thinking used in investigations. It's a rather general goal, but other statements in the map are more specific. AST3 is precisely expressed in the statement "Students can generate conceptual schemas" and "Students can form hypotheses" covers a part of AST4, but not "I test hypotheses". This aspect could be easily be included in the statement "Students can plan observations and experiments" and perhaps also "Students can carry out

[1] Although Hungary is not an S-TEAM partner, there are connections via Mind the Gap

experiments”. AST6 is represented by the statement “Students can find evidence based answers to questions”. The Hungarian map doesn’t specifically address AST7-10.

Turkey’s Literacy Connections to Scientific Thinking through Inquiry

The Fundamental Aspects of Science Thinking (FAST) aren’t represented directly in the Turkish map. However, the content of the following statement ”The student should be able to develop skills for conducting experiments and evaluates experimental data to reach generalizations” contains prerequisites for central skills in FAST. This statement’s last part can be related to AST6. This aspect is also supported by the statement expressing ”The student should be able to understand that science has a structure that is based on evidence and it allows questioning and falsification” and the focus in this statement on questioning and falsification also connect it to AST8. The reflection over use, challenge and change of scientific concepts and theories, which is the core of AST8 is also represented in the statement ”The student should be able to evaluate the role of continuous testing, reviewing, and criticizing in the development of science and technology”. This objective also has elements of AST11. However this aspect is more clearly related to the statement ”The student should be able to explain the importance of sharing scientific and technological results through appropriate communication contexts” as well as in the statement ”The student should be able to state the results of observations, experiments and research orally and verbally”. The Turkish map also focuses on the forms of visualisation in ”The student should be able to express experiment results with tables and graphics, interprets tables and graphics”. As in most other analysed maps, the Turkish map doesn’t have nodes or statements representing either AST9 or AST10.

France’s Literacy Connections to Scientific Thinking through Inquiry

The overall impression of the French map is that it is very detailed and that the arrow between the nodes ‘student’ and ‘know’ is very thick. The national statement also supports this impression, with its focus on knowing a lot of scientific facts. However, a closer look at the map reveals several statements that are related to aspects of scientific thinking. The statement “The student must be able to put in practice a scientific approach” is very good evidence of the existence of these aspects in the French map. The objective covers almost all the AST aspects, but it is not very specific. Other statements focus more one aspect like AST5 in “The student must be able to understand that an effect might have several causes acting simultaneously, and to perceive that there might exist unapparent or unknown causes” or a couple of aspects like AST6 and FAST in “The students must know how to observe, to interrogate, to express a hypothesis and to validate it, to argue, to elaborate elementary models”. AST11 is likely addressed by the first part of the statement “The student must be able to express and to use appropriately the results of measurements or of any research”, whereas the last part is more related to AST6. As with other national statements, the French is without any representation of AST9 and AST10. In addition the French statement of national Scientific Literacy does not address AST7.

Overall view of National Literacy Statements' Relationship to Scientific Thinking through Inquiry

Most of the national statements, as seen through the concept maps, emphasise the importance of student activity, not only as a pedagogical tool but also as an important goal to achieve scientific literacy. Differences between typical practice and the inquiry pedagogy called for in these scientific literacy statements provide opportunities for Teacher Professional Development. The following are some examples from map-statements and national statements.

The Danish map has a very bold arrow from ‘student’ to ‘carry out’ and also to ‘use’ and these verbs are in statements that focus on investigations. The national statement contextualizes these statements by saying: “This activation of students in practical work is a century old cornerstone of Danish science education tradition and has a strong presence throughout Danish elementary and secondary schooling.” However, this activation is often very much controlled by the teacher. The focus on making models and establishing simple hypotheses in the Danish scientific literacy goals that call for openness of investigations are not deeply rooted in Danish science teaching and hence are important for further Teacher Professional Development.

The verbs in the Scottish statements presuppose student activity in order for students to carry out investigations, but the Scottish map doesn’t contain any statements or nodes that can be related to the degree of openness in student investigations. Also the national statement is without any considerations about this dimension, again providing demands for Teacher Professional Development.

The Israeli map also contains verbs that presuppose a constructive approach to teaching. The statement about students thinking critically and independently and the bold arrow students should be able to cope with problems relating to student work with investigations. However it is not clear whether these statements should be based on empirical work or textbooks. Neither does the Inquiry Based Science Teaching section in the national statement clarify this.

The French map has a major focus on facts that the student should know. Another focus is on student development of a rational apprehension. The goal of the former focus could be taught with or without student activity (the national statement does not reveal a pedagogical approach). The latter focus leads to statements containing words such as 'observation and critical sense', 'observance' and 'curiosity', which indicate a need for student activity and for openness of investigations. The statement 'The student should carry out hand-on experiments' also points towards student activity and could also include openness of investigations.

The English/Welsh national statement includes the phrase "… offers examples for teachers or teacher trainers to implement the national curriculum using inquiry-based science teaching methods" which is supported by the fact that the arrow between student and use is the thickest in the map (leading to statements with nodes like tools, data and evidence). The statements such as "Student can collect first hand data" and "Student can evaluate in collecting scientific data" points towards a high degree of openness in investigations.

The Turkish national statement describes the new curriculum's objective as "… to engage students as an active learner while conducting inquiries and prepare them to be scientific[ally] literate citizens." This is followed by "The new curriculum promotes Inquiry Based Science Teaching (IBST) and advocates a constructivist approach to learning science." This clearly places the Turkish curriculum as a curriculum with focus on student activity as a means and aim and with a focus on a high degree of openness in investigations. However, the national statement also admits that "… many science teachers do not fully understand the new Science Curriculum including the nature of IBST and how to put these ideas into their classroom practice". The Turkish map has statements that follow up on this focus e.g. "Student can use theory and model to predict and describe physical events".

The overall picture of the Hungarian map and national statement is that students should learn specific science content, almost neglecting a focus on student competencies. However small parts of the map point to a student activity focus with statements like “Students willingly engage intellectual inquiry”, “Students reflect critically…”, “Students become creative and active citizens”, “Students generates conceptual schemes”, “Students form hypotheses” and “Students plan and carry out experiments”. These statements’ centre on student activity and on a high degree of openness in investigations which is also emphasised in the national statement: “… since 1989, processes of science which require thinking as well as knowing, have been added to the Hungarian statements…”.

Increased Intrinsic and Extrinsic Motivation for/with Fresh Pedagogies

We found in the Mind The Gap workshop trials that once teachers immersed themselves in the demands of their Scientific Literacy statements, their intrinsic motivation to adopt (in the case of novice teachers) or adapt (for experienced teachers) methods consistent with the multi-dimensional nature of the objectives, increased. So they were, for example, curious about inquiry teaching methods, which would help them realize science process objectives, and hence readily experimented with, and tried out such strategies. For some, there was also increased extrinsic motivation that came with the realization that they had a professional obligation from their educational leaders to successfully meet the objectives of the Scientific Literacy statements.

Concomitantly, both intrinsic and extrinsic motivation may increase among students taught with a variety of methods, including inquiry, designed to meet the various demands of Scientific Literacy. In many countries, science as it is normally taught is not motivating for the students. Teaching for Scientific Literacy, by using investigations of problems related to student’s interests and close to current world events, can increase positive student attitudes and therefore their engagement with learning. For example, in Figure 2, a Danish Scientific Literacy objective beginning with ‘use’ calls for students to be able to ‘use models to qualitatively and quantitatively describe relationships in nature’. To meet this goal, teachers could be motivated to design an application of modelling to real-world situations, where students themselves create simple models using computer software designed for showing relationships. The fact that the SL statement calls for student action through ‘use’ and a relationship to the world through ‘natural relationships’ has the potential to increase student motivation to work and learn.

When students are motivated, engaged and learn efficiently the feelings of self-efficacy among their teachers is increased. Teachers whose teaching efforts are rewarded with success naturally feel more confident about their ability to teach effectively. Higher teacher self-efficacy is associated with more innovative and student centred teaching, including inquiry teaching (Czerniak,1990). Through multi-modal inquiry based science teaching, motivated by demands of Scientific Literacy objectives, our goal is to give teachers theoretical and practical tools to provide their pupils with a variety of activities comprising an embodiment of knowledge but also autonomous tasks where they can develop their expressive and metacognitive skills, including their control of scientific thinking.

Broadening of Science Teaching to Include Citizenship Goals

Scientific Literacy statements are the products of cultural systems and consequently influenced by political issues. This cultural origin and perspective is a useful tool in Teacher Professional Development since it can motivate teachers to include perspectives on the interdependence of science and culture into their teaching. Many national literacy statements include applications of science to society including contributions to citizenship. For example in Figure 3 from the Scottish national statement, it is clear that the objective that says ‘A scientifically literate person develops self-awareness and reflection [about science that is] applied to society’ offers teachers the opportunity to extend science beyond the accumulation of vocabulary and formulae. The fact that inquiry-based teaching methods provide an ideal pedagogical platform from which to create problem-based applications of science to the community furthers the potential impact of Scientific Literacy statements on teacher development.

Furthermore, inclusion of citizenship in the science classroom can easily lead to cross-disciplinary lessons as advocated by various nations. For example, in Denmark, there is extensive project oriented work, which is always cross-disciplinary, commonly including a science topic with those of other disciplines. Approximately ten percent of upper secondary time is spent on such cross-disciplinary work through which science literacy is supported through its relevance to other content areas. For example, links to science can be found in Danish literature studies in which student essays can be assigned to scientific issues and then read by language and science teachers, further promoting scientific literacy. Each upper secondary school actually has ‘streams’ or inter-disciplinary topics, which include three subject areas. Every student contributes to projects related to these streams and since the streams often include a science course, there is considerable opportunity to achieve Scientific Literacy goals through cooperation with other disciplines.

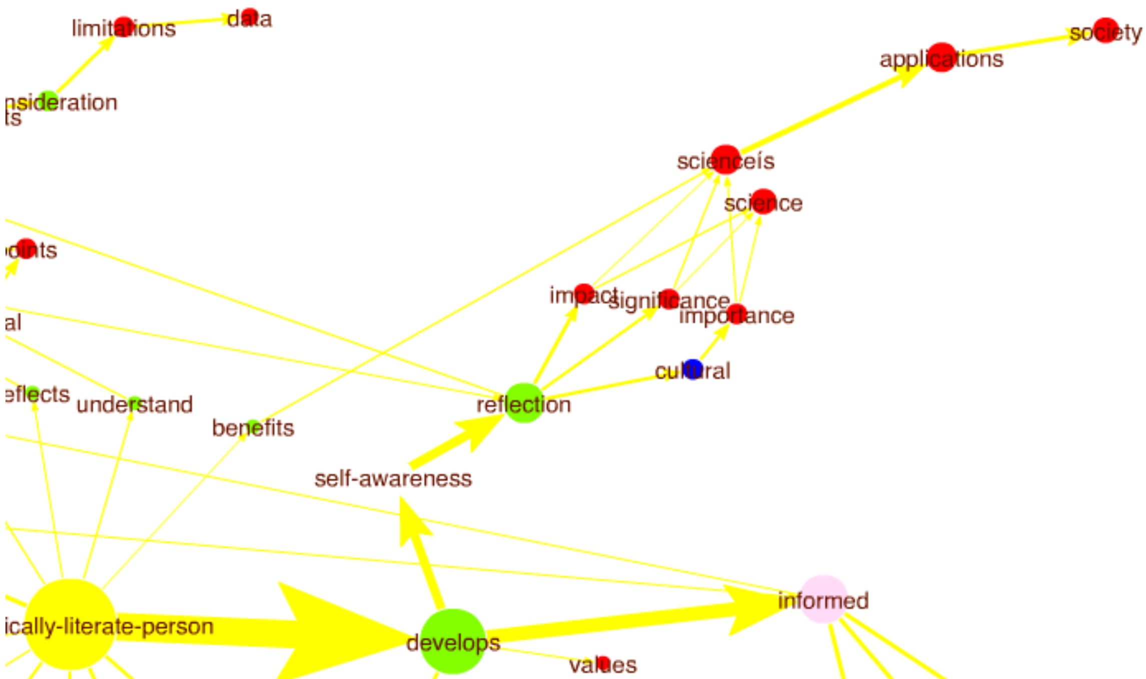

Figure 3. Detail from the Scottish national statement of Scientific Literacy.

Stimulation through International Science Issues

In the evolution of our Mind The Gap Teacher Professional Development workshops, we found that having teachers consider the contents of other national statements of Scientific Literacy in addition to their own was a useful precursor to activating inquiry-based teaching. National calls for science teaching for citizenship are only enhanced when considered from various national platforms since the culturally relativistic nature of applications to local citizenship lead to more realistic EU-wide considerations. Scientific issues when addressed from an international perspective lead to greater meta-reflection since each culture has different perspectives that are best addressed through inquiry methods where students apply organized methods to investigate and recognize patterns in their observations of cross-cultural issues. For example, cloning animals for food is currently banned in Denmark but allowed in most other EU countries. Such an issue has an ethical basis in the context and culture of each nation, some of which is revealed in national scientific literacy statements.

Teacher understanding of other culture's scientific literacy emphases can lead to more variety of inquiry teaching since inspirations from other perspectives can add both to teachers' content knowledge and their process of science repertoires. A wider awareness of scientific literacy demands can serve to insure that teachers do not miss opportunities for inquiry because their own cultural lens does not happen to include them.

Multi-modal Literacy Leads to Greater use of Inquiry

Scientific literacy involves seeing science in different lights and from different viewpoints. Our individual deliverables suggest different ways of viewing and engaging in science, such as through drama, media coverage, objects and dance. Multi-modal literacy (MML), embraces not only verbal language but also these other semiotic tools, which can be combined in clusters to intensify learning (Kress, 2003, Kress & van Leeuwen, 1996). Most statements of Scientific Literacy virtually require MML approaches to teaching since the variety of skills and competencies demanded are not easily met with only verbal language. In turn, MML promotes scientific literacy in that the nature of science is more fully experienced and understood from the diverse perspectives of MML. The likelihood of MML leading to inquiry is greater than with just verbal language communication (Kress, 2003) because the semiotic mediation through signs in different modes, often simultaneously used in clusters, adds to the cognitive load of Scientific Literacy concepts and thereby provides valuable tools for inquiry based teaching. Dance, theatre and hands-on, all add to the cognitive load and hence more constructivism is needed for learning, with a resulting enriched cognitive output.

Student Centred Teaching

One of the most evident aspects of national statements of Scientific Literacy is the focus on students. A glance at each of the statements mapped at
[http://www1.ind.ku.dk/mtg/wp3/scientificliteracy/maps/4]

shows either ‘students’, ‘the budding researcher’ or ‘scientifically literate persons’ at their centres. These statements and the resulting maps clearly indicate the centrality of student centred learning in every country. Connected to these ‘learners’ are action words requiring pupils to take an active role in acquiring literacy. With these verbal and visual emphases, teachers who have been taught to scaffold lessons consistent with at least one statement of Scientific Literacy, naturally centre the student in those plans. Not inconsequentially, literacy maps contribute to perceptions of the centrality of acting students in science classrooms. The chances of engaging lessons resulting from this view are likely to be increased over the content centred curricular statements often encountered in Ministry of Education curriculum objectives.

Teaching Consciously for Indigenous Group Sustainability

By specifying science literacy goals which include a context for teaching about indigenous populations, Scientific Literacy statements can add an important societal perspective to learning goals. For example, in the Norwegian statements of Scientific Literacy there is a demand for teaching that considers the sustainability of indigenous people from a scientific perspective. The heightened awareness from these statements, both for Norwegian teachers and for those of other nations without such explicit statements, can lead to lesson plans that address the needs of this group and others. The goals provide another cross-disciplinary platform for science education and chance to meet citizenship goals.

(http://www1.ind.ku.dk/mtg/wp3/scientificliteracy/maps)

Inquiry teaching is a likely choice for meeting such objectives since it allows for the constructivist consideration of complicated social and scientific factors which affect sustainability. Such literacy goals are not genuinely met with factual transmissive teaching since they are not about set answers to problems, but rather about the acquisition of thoughtful approaches based in science but applied to the world. A concomitant outcome of learning about sustainability constructively is for students to 'take-on' the perspective of indigenous people.

Enhanced Life-long Learning from Teaching

EU legislation includes a group of 'Key competences for lifelong learning'.[2] Amongst them are:

Basic competences in science and technology. Basic competences in science and technology refer to the mastery, use and application of knowledge and methodologies which explain the natural world. These involve an understanding of the changes caused by human activity and the responsibility of each individual as a citizen.

Social and civic competences. Social competence refers to personal, interpersonal and intercultural competence and all forms of behaviour that equips individuals to participate in an effective and constructive way in social and working life. It is linked to personal and social well-being.

[2] http://ec.europa.eu/education/lifelong-learning-policy/doc28_en.htm

Most EU statements of Scientific Literacy include some objectives directly targeted at each of these competences. See examples at:

[http://www1.ind.ku.dk/mtg/wp3/scientificliteracy/maps/4].

Consequently, for the science teacher who may or may not feel connected to the enhancement of life-long learning, Scientific Literacy statements provide a useful guide to how to do that. Life-long learning as described by these competences is only partially based on the acquisition of science content knowledge. Rather, the highlighted words above call for the active use of science throughout life. Such active use of science is most effectively taught and modelled through inquiry learning where students, usually in small groups, find solutions to problems using science.

EU Perception of Scientific Literacy

When teachers, and through them their students, encounter the Scientific Literacy statements of their own culture and those of other nations, an understanding of how varying cultural contexts contribute to scientific literacy actually enhances literacy within each country. Scientific Literacy maps provide an easy (semi-abstract) way to explore alternative literacy statements for both shared and new ideas. This broader EU perception of what literacy means is easily included in inquiry activities that engage students as citizens and in the many issues such as the environment, nutrition and energy, which span the EU.

The PISA assessments are one arena where the EU already 'shares' a common Scientific Literacy statement (see Figure 5.) Understanding these common statements, particularly when compared to national statements is useful for teachers interested in meeting PISA literacy objectives in addition to those of their nation. Such an understanding can also be useful in determining where varying emphases between PISA and national statements may result in student difficulties with certain PISA questions. An overall understanding of the different ways in which scientific literacy is viewed in different countries and within different cultures, can help move the EU towards a unified understanding of scientific literacy within its culture and move towards a new concept of science education in Europe. This does not mean that national statements will be superseded by EU or PISA statements, but rather that areas of shared goals will be known and unique cultural emphases will be understood and used to generate fresh perspectives. In both cases such a wider EU understanding can help scaffold and target Teacher Professional Development throughout the EU.

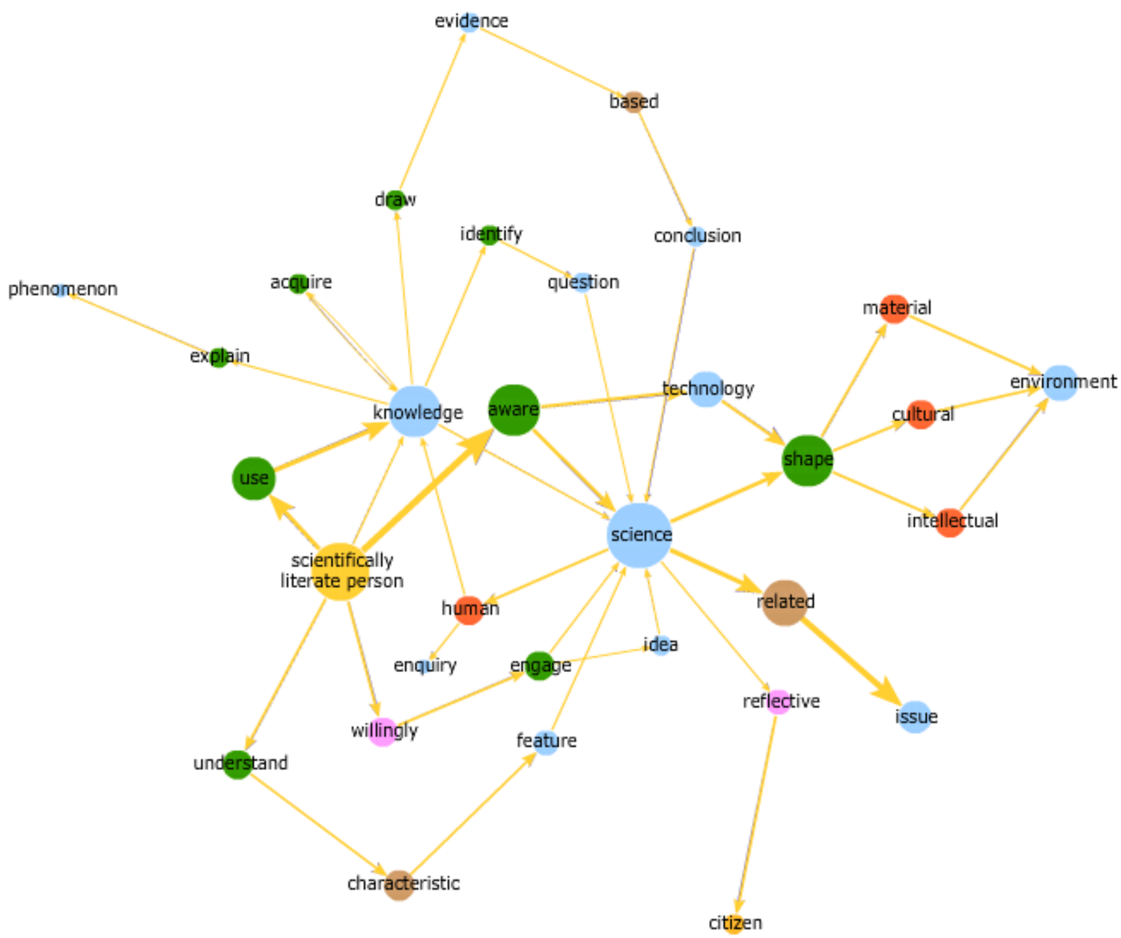

Figure 5. PISA 2006 statements of Scientific Literacy.

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Some Thoughts On the WP8 Overview Report

Colin Smith, University of Strathclyde

Note: this section is a commentary on the Scientific Literacy paper (above) and is part of a continuing dialogue within the project about how Scientific Literacy can be deployed in Teacher Professional Development and the classroom, in order to promote the S-TEAM objectives of enhanced engagement with science and improved recruitment to science careers.

Scientific Thinking (Adapted from Feist, 2006)	
Aspect of Scientific Thinking (AST)	**What it involves**
1 *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
2 *I categorise what I observe as things and events*	Classifying information from observations into meaningful concepts or systems of concepts
3 *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)
4 *I form and test hypotheses*	Arises initially from pattern recognition. Begin to expect world to behave in certain ways and test these expectations
5 *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.
6 *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.
7 *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 (Adapted from Feist, 2006)	
Aspect of Scientific Thinking (AST)	**What it involves**
	scientific thinking.
8 *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.
9 *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 focusing strategies
10 *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 look for evidence and arguments against it.
11 *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

Scientific Thinking (Adapted from Feist, 2006)	
Aspect of Scientific Thinking (AST)	**What it involves**
	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.

Table 1: Aspects of scientific thinking[3]

Summary based on WP8 scientific literacy overview report						
Denmark	France	Hungary	Israel	Scotland	Turkey	UK (Eng/Wal)
1 2 3 4 5 6 7 8 11	(1) (2) (3) 4 5 6	(1) (2) 3 (4) (5) 6	(1) (2) 3 (4) 5 (6) (8)	(1) (2) (3) (4) (5) 6 8 11	(1) (2) (3) (4) (5) 6 8 11	(1) (2) (3) 4 5 6 7 8

Table 2: Summary based on WP8 scientific literacy overview report

Notes: The numbers refer to the aspects of scientific thinking (AST1 to AST11). Numbers in brackets refer to those that seem to be implied by the national scientific literacy statements, rather than explicitly mentioned.

Discussion

We should remember that possibly, as is the case for Scotland, each national statement on scientific literacy is only part of the documentation that outlines the rationale and experiences and outcomes that the science curriculum aims to provide. Considering national differences about the science curriculum only on the basis of these statements carries some risk.

That said, what is interesting is the way that different countries conceive of scientific literacy itself, if we analyse their statements by using the aspects of scientific thinking.

No countries mention explicitly or implicitly AST 9 and 10.

[3] From Smith et al, 2010, this document, pp.118-149

This is not surprising for AST10. There are likely to be few cases in school science when the opportunity to formulate genuinely new theory will occur. However, it is not impossible to imagine that such occasions could occur, if only rarely and in occasional very open investigations. This might be something that teachers and curriculum developers might want to consider.

The absence of AST9 seems more serious. For example, if the use of analogy by scientists to draw connections between past successful experiments and those that they are currently planning is important to them (Dunbar & Blanchette, 2001), it is also important to our young people when we ask them to design their own experiments to test hypotheses or ideas. The absence of this in scientific literacy statements, if repeated in the rest of the national documentation, suggests that analogy of this type, and others, is being overlooked – an oversight likely to also run into classroom practice. This is, perhaps, something that we should focus more specifically upon in this project, and which we should actively encourage practitioners and teachers to consider. It might be an important strand for ITE, also. How do we structure teaching to focus on the analogies that we use and to help our young people form their own?

Similarly, with regard to metaphor, Lakoff & Johnson (1980; see also 1999) were instrumental in bringing to widespread attention the way in which metaphor permeates all our thinking (see also Gibbs Jr, 1994), and science is no exception (Cameron, 2002; Sutton, 1992). Sutton makes two points about metaphor that seem important here.

Firstly, to choose an alternative metaphor can be akin to choosing an alternative theory. If so, when asking our young people to explore theories (their own and established ones), we should find ways to get them to focus on the metaphors that they are using and why they are useful. Similarly, we should remember another of Sutton's points, which is that metaphors become dormant. For example, 'cell' was originally used to describe what early microscopists saw as an array of compartments (like monk's cells or the parts of a honeycomb) but subsequently became a literal name for a biological unit. Sutton suggests that teaching should involve activating these dormant metaphors.

Cameron discusses the difference between metaphors used to explain concepts in teaching and those that are part of the theory, or have been used in building it. She is concerned with the former, but recognises the importance of the latter. However, some of the problems with metaphor that she discusses (for example, misinterpretation, perhaps due to prior knowledge) seem equally pertinent for theory building metaphors. Again, and given its seemingly undeveloped conceptualisation in our curricula, perhaps we should focus more upon metaphor as a contribution to the development of science education policy, practice, TPD and ITE.

It is interesting that only one national statement on scientific literacy seems to specifically mention all of the more fundamental aspects (AST1-AST5 – referred to as FAST in WP8 2010), although they can be argued to be explicit in the others. However, it is here that one has to be careful. The Scottish documentation, for example, explicitly contains these aspects of scientific thinking in its "Experiences and Outcomes" document. Some statements seem more content focussed (e.g. France) in their view of scientific literacy and others (Denmark/ Scotland) more focussed on its role in the process of being a citizen in a social democracy. Even so, there are differences to be understood, such as the above-mentioned fact that FAST is directly involved in scientific literacy in the Denmark statement but only implicitly in the Scottish one, with it being more prominent elsewhere. Is there potentially a more general conception of scientific literacy that we can share, which incorporates all the aspects of scientific thinking and that can then be developed to fit different national contexts and aims?

It is also interesting that AST6 seems explicit in all but Israel, where it is also implicit. This aspect would seem to involve a pretty high or sophisticated level of thinking. I am not sure that assessment practices used in Scotland or elsewhere would capture it.

In fact, many of the aspects seem difficult to capture in assessments. What other evidence do we have that they are being supported and achieved?

In addition, we have to remember that the aspects are just that, ‘aspects.’ They are not, strictly speaking, isolatable. Take, for example, an apparently simple aspect like AST1 – observation. As stated, it looks quite simple but senses may need supplementing in science with instruments. Use of these instruments presupposes having concepts. A ruler presupposes concepts such as height and length. Some of the concepts are more abstract and depend upon theory. A Geiger counter presupposes a concept of a form of radiation (alpha) that we cannot see and which derives from atomic theory. In reality, there are complex, interactive or iterative relationships between the aspects. This may be partly what makes them difficult to capture in assessments. It certainly requires us to think through in more detail the relationships between the aspects of scientific thinking and the significance of these for practice. Finally, how much attention should we pay to phrases in the scientific literacy statements that have not appeared in our analysis as relating to scientific thinking? There is plenty to think about!

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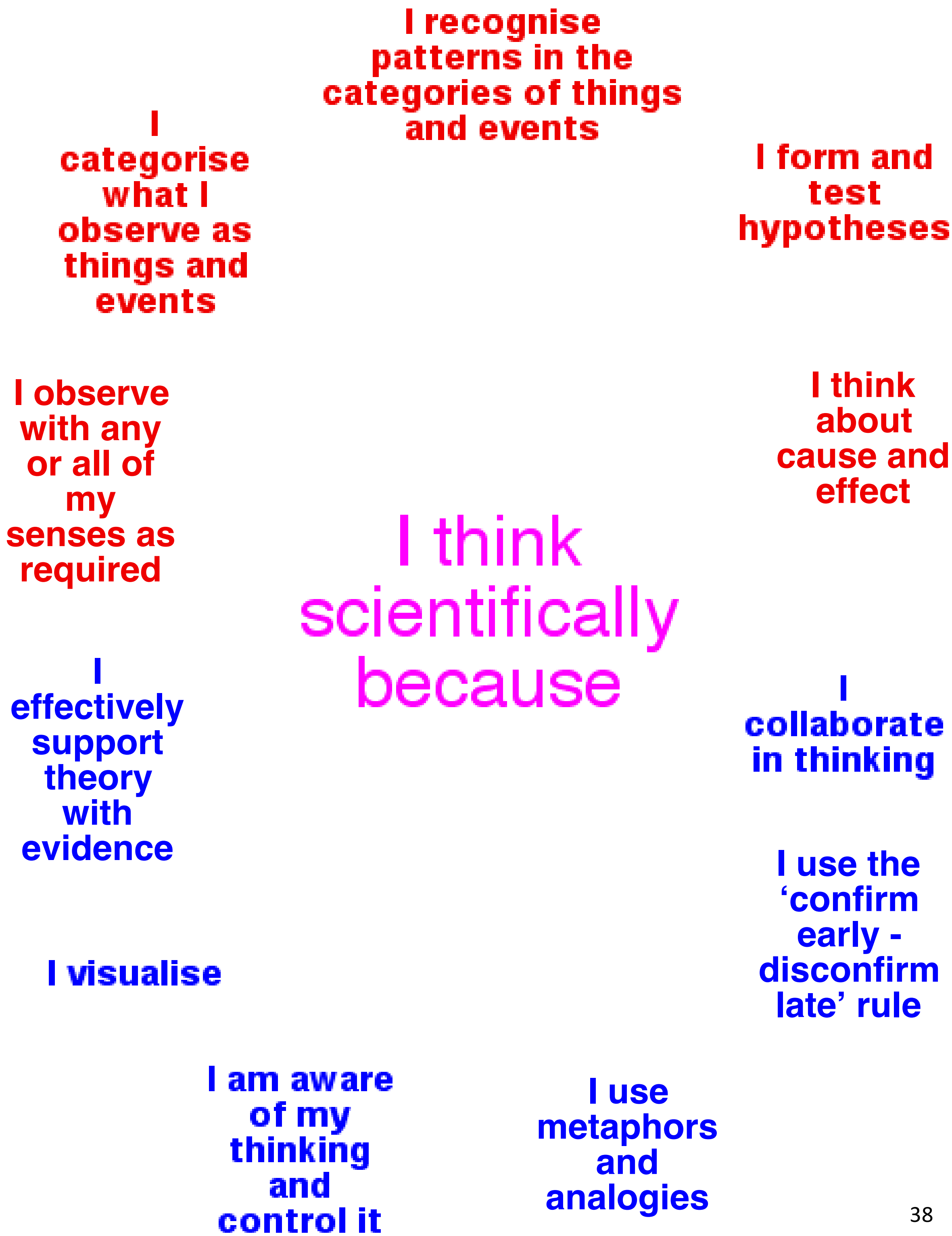
Support for scientific thinking in school science investigations: A Teaching Tool

Colin Smith

Fearghal Kelly

Sinclair Mackenzie

Figure 1: Scientific thinking tool in visual form



Section1: 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 (Figure 1, above, 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 formal investigations (Standard Grade and Higher), common course work experiments and more open investigations conducted by our pupils (see the sections containing examples later). 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 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).

Section 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 although 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 a 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 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 focusing 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.

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, 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.

Section 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 better 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[4], 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

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 investigative booklet on previous occasions.

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

[4] These levels refer to the Scottish examinations normally taken at ages 15-16 and 16-18.

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 deep scientific thinking.

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

Example 2: Analysis of Higher Investigation

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.

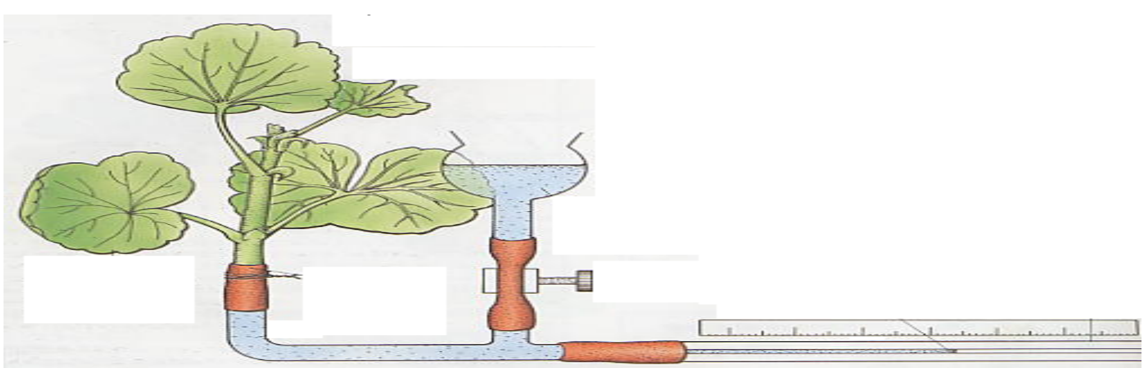


Figure 2: A bubble potometer that can be used to investigate evaporation of water from leaves.

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

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.

Table 5 cont'd: Analysis of Higher Investigation (A transpiration investigation using bubble potometer).

Dimension of Investigation	Aspects of scientific thinking)	Analysis
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 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, or variations on them, shown in Figures 3-6. that can be found in Scottish textbooks (e.g. Torrance, 2001) and be presented as testing the validity of the equation for respiration.

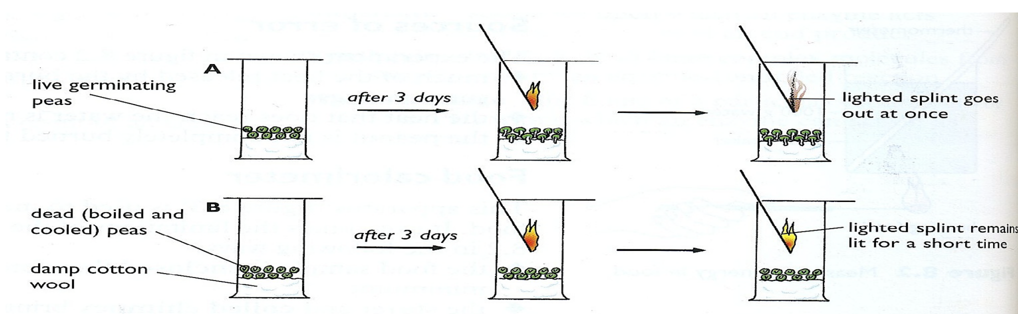


Figure 3: Oxygen uptake (Torrance, 2001, page 72)

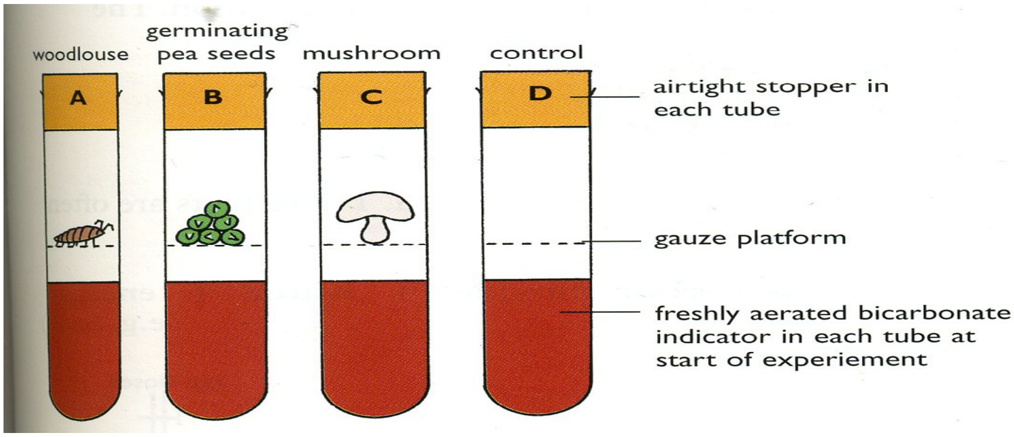


Figure 4: Release of Carbon dioxide in respiration (Torrance, 2001, page 73)

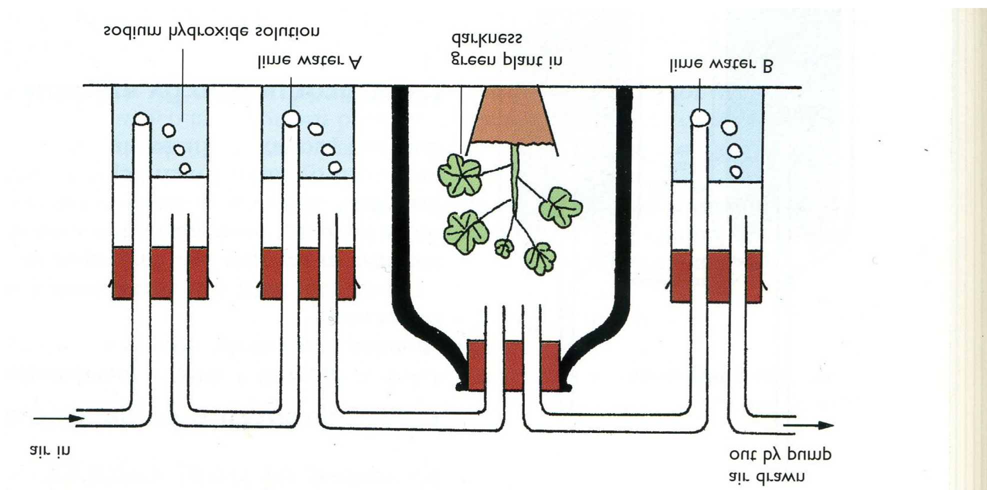


Figure 5: Release of Carbon dioxide by green plants (Torrance, 2001, page 73)

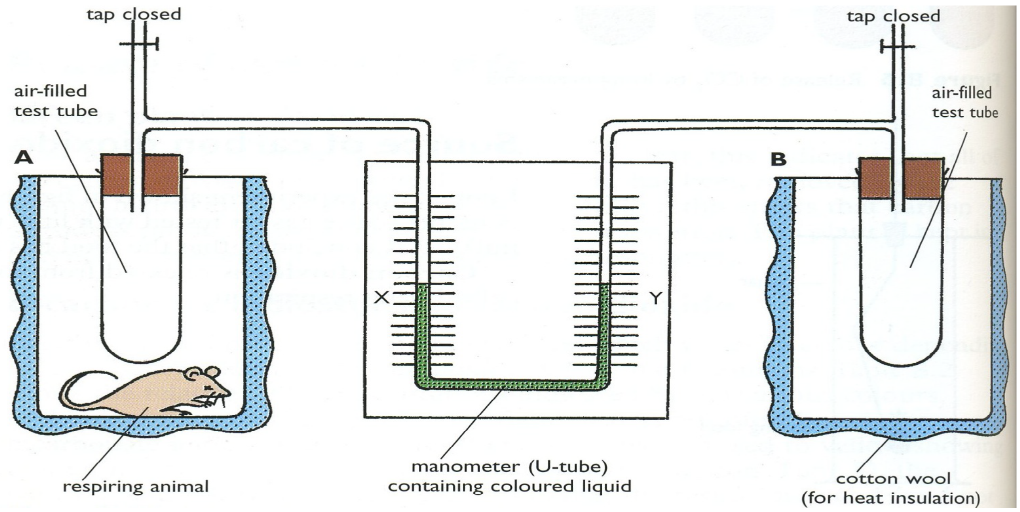


Figure 6: Release of heat by respiring animal (Torrance, 2001, page 74)

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, this example, as so many of the aspects involve effective support by the teacher, 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 investigation**.*	*I observe with any or all of my senses as required*	Supported as pupils have to observe the results of each experiment.
	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 by guided by the tacher 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-	Not supported

	disconfirm late' heuristic	
	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 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.

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 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

Table 7 cont'd: Testing models of seeds to investigate factors limiting seed dispersal by wind

Dimension of Investigation	Aspects of scientific thinking)	Analysis
	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.

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.

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.

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

Dimension of Investigation	Aspects of scientific thinking)	Analysis
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. 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.

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

Dimension of Investigation	Aspects of scientific thinking)	Analysis
	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, 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 form 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 may 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.

Section 4: 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 ourselves and our pupils 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.

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The table overleaf has been left blank to copy for your own investigations.

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	.

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