Report

The S-Team project has received funding from the European Community's Seventh Framework Programme [FP7/2007-2013] under grant agreement n°234870.

S-TEAM

Collected papers no. 1

Developing Scientific Thinking in the Classroom Through Inquiry

April 2010

S-TEAM

Collected papers no. 1

Developing Scientific Thinking in the Classroom Through Inquiry

Editor:
Peter Gray

Authors: [1)]
Zozan Kaya Asphaug
Gultekin Cakmakci
Jens Dolin
Robert Evans
Liselott Forsman
Peter Gray
Florence Le Hebel
Doris Jorde
Fearghal Kelly
Berit Kurtén-Finnäs
Sinclair Mackenzie
Jim McNally
Peter van Marion
Pascale Montpied
Sonja M. Mork
Anna-Lena Østern
Ran Pelleg
Colin Smith
Alex Strømme

1) The authors are presented on pp 151 - 154

ISBN: 978-82-93118-04-6

Contact details:

Project Coordinator: Professor Peter van Marion
Peter.van.Marion@plu.ntnu.no

Deputy coordinator: Professor Doris Jorde
doris.jorde@ils.uio.no

Project Manager: Dr Peter Gray
graypb@gmail.com

Project Administrator: Hilde Roysland
hilde.roysland@svt.ntnu.no

S-TEAM website: www.ntnu.no/s-team
Postal address:
S-TEAM
Program for Teacher Education
NTNU
Dragvoll Gård
N-7491 Trondheim
Norway

Published by NTNU (*Norges teknisk-naturvitenskapelige universitet*), Trondheim,Norway

The S-Team project has received funding from the European Community's Seventh Framework Programme [FP7/2007-2013] under grant agreement n°234870

Published under an open-access agreement with the European Commission

Citation:

S-TEAM (Science-Teacher Education Advanced Methods) (2010) *Developing Scientific Thinking in the Classroom through Inquiry,* Trondheim, S-TEAM/NTNU, available at: http://www.ntnu.no/s-team

Table of Contents

General Introduction

This document is the first component of a suite of S-TEAM training packages in science teacher education. It includes two examples of S-TEAM products from Work Package (WP) 6, one of which (6.10) is directed at classroom practice, whilst the other (6.12) is aimed at the systemic level. In addition, we have included preliminary material from other work packages, which provides additional background to the current S-TEAM activities:

An introduction to the Viten project, which is a web-based resource for teachers,

A guideline to the implementation of inquiry in the classroom, for use in Initial Teacher Education (ITE).

A discussion document on scientific literacy,

The prototype of a tool for assessing the level of scientific thinking taking place in inquiry-based classroom activities,

These preliminary components will reappear in an updated form in future training materials (deliverables 5a and 8a, due in October 2010) but are included here as an example of the kind of work currently taking place within S-TEAM. They are also included to illustrate the emerging process of cross-partner collaboration, which is, to some extent, hidden behind the work package structure of S-TEAM.

The emerging concepts of S-TEAM at M12

Although the work plan of S-TEAM is proceeding in accordance with the original intentions of the project, it was inevitable that its many meetings and collaborative activities would generate new ways of thinking about science education and science teacher education. It is clear that inquiry should be a central concept in science education. It is also clear that there are many variations on the theme of inquiry, and that it is not always easy to recognise when and where it occurs. In relation to the S-TEAM aims and objectives, the essential aspect of inquiry is that it should encourage scientific thinking. In the classroom, inquiry may be fostered through investigative working methods. The additional papers reflect our ongoing discussions on the nature of scientific thinking and its manifestations in classroom activity.

We have also included a preliminary paper on scientific literacy, which will reappear in its final form at M18, as a WP8 deliverable. It appears here in order to provide a sense of the connection between scientific literacy and scientific thinking.

Due to the wide variety of contexts in which training or other teacher education and professional development activities can take place, the materials produced by S-TEAM are designed to promote informed debate rather than be prescriptive. Our initial experience from the national workshop programme conducted in autumn 2009 suggests that space can usefully be made for constructive debate in national contexts by introducing materials such as those presented in this document and the related video resources.

S-TEAM is currently planning activities to disseminate its existing materials. The national workshop reports (del.2a/3a) tell us that teacher professional development (TPD) in Europe is fragmented and does not provide sufficient support for the systematic introduction of inquiry-based and other advanced methods. Whilst there are many individual examples of good practice, these are not always connected either to teacher career development or to long-term improvements in teaching methods and pupil outcomes. S-TEAM will continue to work with national partners to create coherence between the available learning opportunities for teachers and teacher educators, and existing models of ITE and TPD.

We are currently in contact with the SCIENTIX project for a European Information Provider in science education, and we expect that the materials in this document will become available through SCIENTIX following its launch in May 2010. They will also be available through the S-TEAM website at:

www.ntnu.no/s-team

S-TEAM Product 6.10: Training package on use of open investigations and Vee-heuristics within science education

Liselott Forsman & Berit Kurtén-Finnäs

Åbo Akademi University, Finland

Introduction

This section provides background material on a web-based course package from the Abo Akademi Resource Centre in Chemistry Didactics on the use of open investigations and Vee-heuristics within science education. This includes guidelines on how the learning of both content and language of students from non-mainstream backgrounds can be supported in this work process.
The web-based material can be accessed from:

http://stream.vasa.abo.fi/flash/tritonia/kurten.php?file=kurten/0.flv

The material is primarily based on work by Kurtén-Finnäs (2008). For the work with the linguistic and cultural dimensions, Forsman has experience e.g. through ongoing research in multilingual settings in Swedish-medium schools in Finland (see description of research, so far only in Swedish, on http://www.vasa.abo.fi/pf/flis/).

Currently the video material has Swedish dialogue with English subtitles.

Open-ended investigations and V diagrams

An open investigation can be defined according to the degree of openness and the demand for inquiry skills (see e.g. Hegarty-Hazel, 1990, p. 375). Open investigations are characterized by the following features:

The educational process is less teacher directed,

More planning takes place in the classroom,

More focus is placed on the scientific process,

There are more topical discussions between students in the classroom,

The students themselves are more active and initiate more ideas of their own (Tamir, 1991, p. 17).

When the students conduct investigations that they have planned by themselves, they can both make use of and further develop their conceptual knowledge, as well as their knowledge of how investigations are conducted (Duggan & Gott, 1995).

Gowin's knowledge-V (V diagram or Vee-heuristics) is a tool for problem solving, where the activities and different steps integral to all types of research are made visible, also the type of research that constitutes an open investigation (Novak & Gowin, 1984; Gowin & Alvarez, 2005). V diagrams were originally developed in order for students and teachers to develop a better understanding of what takes place during investigations in the science classroom. The structure of the V diagram mirrors human thinking and how humans develop new knowledge and understanding (Novak, 1998, pp. 80-82).

The material is to be used as a starting point for classroom work within teacher education and continuous professional development with the aim of increasing understanding of how open investigations and V-heuristics can be used within science education, including how the learning of students from non-mainstream backgrounds can be supported.

Work with open investigations in combination with V-heuristics has the possibility of affecting the students' interest and self-image in a positive direction. Students working in groups with problem solving can develop their understanding in dialogue with their peers and with the teacher (Kurtén-Finnäs, 2008). The students can experience the thinking process as a positive part of the investigation, and their own planning can contribute to a feeling of ownership and agency.

For students with a non-mainstream background, there are learning benefits both regarding language and content development. This is connected to work processes that integrate abstract conceptualization with concrete actions through being more experiential, and which provide the students with more opportunities for discussion and multiple sources of knowledge through being more dialogical and less teacher directed (see e.g. Carrasquillo & Rodríguez, 2002; Coelho, 1998; Cummins, 2000; Hajer, 2000). The use of V diagrams during investigations can support the learning of all students due to its clear graphical structure, which serves as a guiding light throughout the investigations. Through the course package, teachers can also learn how to take further steps when introducing new topics, terminology and text to ensure that the pre-understanding of all students is taken into consideration.

Both on-line and face-to-face applications are possible, but we see the most sustainable development possibilities in more extended classroom work with teachers through supervision/ mentoring activities that use the course package as a starting point. Web-based material (in Swedish, to be translated into English) will be used both within teacher education and continuous professional development for science teachers.

Contents of training package (video episodes):

1. What is an open-ended investigation?

2. Introducing an open-ended investigation in class.

3. Students planning their investigations (upper secondary, year 1: *Separate cooking salt, benzoic acid and sand).*

4. Teacher students working with an open-ended investigation (*what is the best dishcloth?*).

5. Concluding discussions about open-ended investigations.

6. What is a V diagram? Theoretical background.

7. Introducing V diagrams in class.

8. Students working with V diagrams.

9. Concluding discussions about V diagrams.

In addition, the website provides a set of guidelines for language support in chemistry education (reproduced below, p.25)

Laboratory work – a background

In many countries laboratory (lab) work is an essential part of the chemistry education, and many teachers cannot imagine teaching science without some kind of lab activity (Bennett, 2003, p. 74; Wickman, 2002, p. 97). In Finland the experimental approach has been stressed in the education of chemistry and physics since the introduction of the comprehensive school system at the beginning of the 1970s (Lampiselkä, Savinainen & Viiri, 2007, p.195). In *National Core Curriculum for Basic Education* (Ministry of Education, 2004, p.192) it is stated that the instruction of chemistry in grades 7-9 “relies on an experimental approach in which the starting point is the observation and investigation of substances and phenomena associated with the living environment”. It is also stated: ”The experimental orientation must help the pupil to grasp the nature of science and to adopt new scientific concepts, principles, and models; it must develop manual skills and abilities for experimental work and cooperation”.

According to Aksela & Juvonen (1999), a majority of the chemistry teachers taking part in their study include laboratory work in their teaching.

The laboratory tasks in Finnish chemistry books are often formulated like recipes for the students to follow step by step (Kurtén-Finnäs, 2000) as in many other countries (see Tamir, 1991; Garnett, Garnett & Hacklin, 1995). As a consequence, investigations become more about handling equipment instead of being opportunities for students to develop their own thinking and understanding (Lunetta, 1998, p. 250).

Open-ended investigations

In an open-ended investigation the students have the opportunity for problem solving in the laboratory and to develop their ability to work scientifically.

An open-ended investigation is defined according to levels of inquiry (see e.g. Hegarty-Hazel, 1990, p.375). In an investigation in level 0, the procedure as well as the answers is given, whereas the answer is unknown in an investigation at level 1 (Table 1). In level 2 the problem is given but the answer is open. However, the students need to figure out how to conduct the investigation and/or plan what equipment they will need to solve the problem. An investigation where the students themselves are to select and formulate the problem, as well as planning how to solve it, is in level 3, the highest level of inquiry.

Table 1. Levels of inquiry in the science laboratory[1]

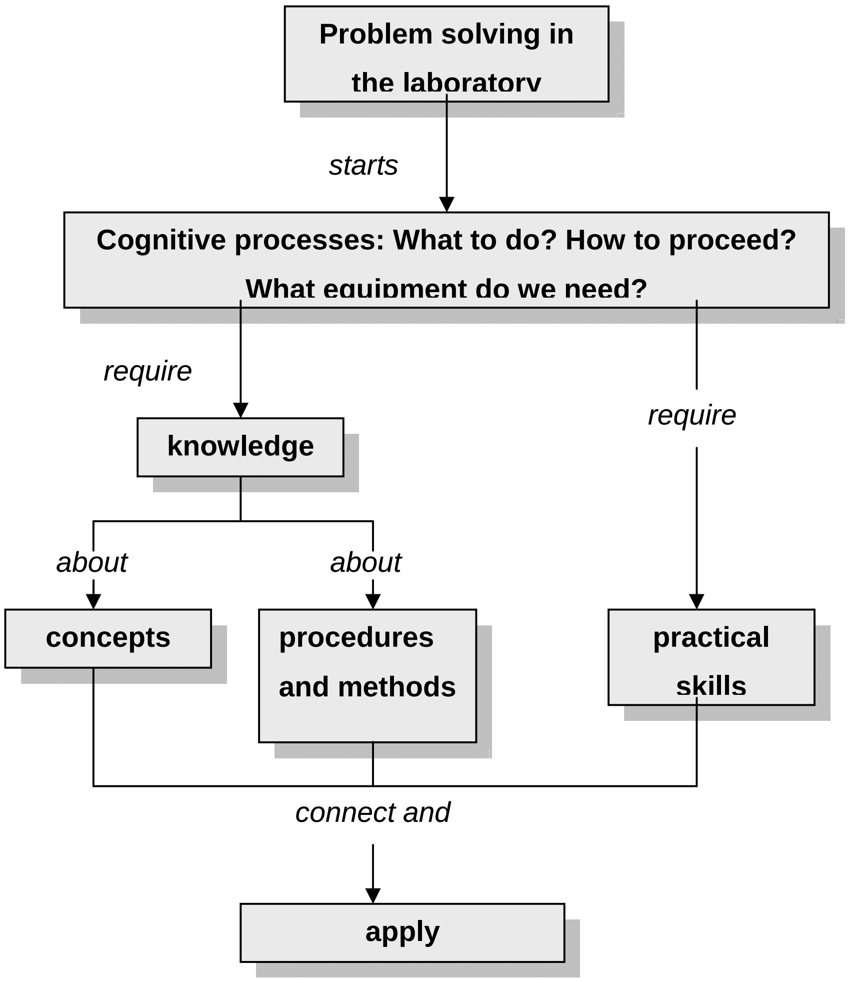
Level of inquiry	Problem	Material	Procedure	Answer
0	Given	Given	Given	Given
1	Given	Given	Given	Open
2 (A)	Given	Given, totally or partly	Open or partly given	Open
2 (B)	Given	Open	Open	Open
3	Open	Open	Open	Open

It is the planning phase and the problem-solving character of the task that distinguishes an open-ended investigation from a traditional laboratory work (Garnett et al.,1995). According to Tamir (1991, p.17), it is characteristic of an open-ended investigation that the teacher is less directive and instead gives more support, the students are more active and initiate more ideas of their own, and there are also more discussions in the classroom. This is confirmed by the results in Kurtén-Finnäs's doctoral dissertation (2008).

Building on a model by Gott and Duggan (1995, p. 25), Kurtén-Finnäs (2001) has described a model for problem solving in the lab. According to this model (Figure 1, overleaf), problem solving in the lab entails that the students activate and make use of their previous knowledge in order to solve the problems. This (previous knowledge) constitutes both conceptual knowledge and insights into how to conduct an investigation, including lab methods such as how to determine/measure pH values, how to perform a titration or how to cause evaporation. At the same time, the problem solving means that the practical capacities of the students are needed for them to be able to conduct the investigation. When the students are posed with a problem that they are to solve themselves and they thereby need to activate their prior knowledge, prerequisites for new and meaningful knowledge-making are created (Glynn & Duit, 1995, p. 13).

[1] Adapted from Hegarty-Hazel, 1990, p. 375

Figure 1. A model for problem solving in the laboratory according to Kurtén-Finnäs (2001), based on Gott and Duggan (1995).



Generally investigations are conducted in the form of pair or group work, which, from a social constructivist viewpoint, can be seen as desirable. When the students work in groups to solve a problem together, possibilities for student-student interactions are created. In communication with others, one strives to build bridges to other people's beliefs and understanding of a situation, a concept or a phenomenon. At the same time one can modify one's own knowledge and construct new knowledge in the interaction with others (Cobb, 2000, p. 154). Since problem solving in groups entails finding a mutual answer to a problem, there is also a need for a mutual understanding of how to solve the problem. In the process of looking for an answer to their mutual problem, the students have the opportunity to verbalize their own understanding, which also can lead to greater awareness of their own thinking (von Glaserfeld, 1993, p. 31). Through formulating their own thoughts there is also a possibility for the students to develop their own understanding of how the problem can be solved. By being confronted with the different viewpoints and conceptions that are expressed in the group discussions, the cognitive development of the individual student is promoted (Hodson, 1988, p. 172). Solving problems in groups gives the students the opportunity to explain and defend their viewpoints, which can stimulate their learning and also affect their motivation in a positive direction (Wheatley, 1991).

Problem solving in collaborative groups involves the repeated rehearsal of successful problem solving attempt. (Clarke, 2001, p.41). Every repetition serves a distinct purpose; at first to identify a possible solution, then to develop a shared understanding of the procedure or to check whether the solution is sustainable.

A fundamental feature of work with open-ended investigations should be that the students themselves in their groups carry the responsibility for solving the task. The students must be allowed to make their own mistakes and have the freedom to perform the task in their own way (Cohen, 1994, p. 2). As the students take on more responsibility they also take over some of the roles of the teacher such as dividing tasks, listening and interacting, and making decisions. An open-ended task will often result in many different experimental designs and differing results between groups (Roth, 1993, p. 159).

New non-traditional roles are required from a teacher working from the students' own investigations in class (Crawford, 2000). The teacher needs to be able to make a diagnosis, to motivate, to guide and to be a scientist, an innovator, a supervisor and a mentor. These are all roles for which teachers do not always have the right education or models. The teacher's understanding of how students learn, e.g. the belief that students learn best from instructions, or that factual knowledge is the most important, will influence his or her readiness to make use of new approaches in the classroom (Cronin-Jones, 1991).

It is the teacher who introduces an open-ended investigation. The way in which it is introduced is critical. Small, seemingly insignificant variations in formulations can have consequences for the task, and for how it is approached by the students (Hacklin & Fairbrother, 1996). For example, the nature of a task with the focus of finding out the best way to keep a piece of ice frozen is different from one where the focus is on comparing and evaluating two methods. The degree of difficulty of the task can be regulated through the way it is formulated. To ask ”Does sugar dissolve better in warm water than in cold?” makes the task less challenging than stating: ”Find out how the temperature affects the dissolving of sugar in water”. If the students are inexperienced and have little conceptual knowledge, it is important to start out with investigations that do not ask for extended theoretical or procedural knowledge (Gott & Duggan, 1995, p. 87). The student’s interest in an open-ended investigation may diminish if the challenge seems insurmountable. However, as the students develop their knowledge, the investigations can also become more challenging.

V diagrams

Usually students see a laboratory work as a practical task to perform (Berry & al., 1999). It is difficult for them to see the connection between theory and practice, and they need to learn from the beginning that an investigation is cognitive work where one’s thinking is supported by the results of practical experiments. The theory of an open-ended investigation has a double role: for one, it constitutes the background for the questions that one is trying to answer and thus functions as a governing factor, but it is also in the theory that the students need to find explanations for their results (Hodson, 1993). For the students to develop meaningful knowledge, it is important that the teacher can help them to create connections between what they know from before, and what they are to find out.

A V diagram is a graphical organizer that can be used as a tool for problem solving. It was originally developed by Bob Gowin as an aid for students to understand the structure of knowledge and how human beings are able to construct new knowledge (Novak & Gowin, 1984, p. 55). The background for this was partly his own interest in philosophy and epistemology, and partly the challenges experienced by many students in relation to research reports. Students might feel insecure and frustrated since they do not really understand what they are doing or what they are supposed to find out, or in what way an investigation is connected to the theory. The students themselves seldom make a conscious connection between relevant concepts, principles or theories and their results in an attempt at understanding why specific events or objects have become the focus of attention. The V diagram has proven to be useful for work with open-ended investigations through its guiding structure. A laboratory report in the form of a completed V diagram goes into more depth than lab reports in general (Trowbridge & Wandersee, 1998, p. 114). In a V diagram, flow charts and concept maps can be included to clarify and visualize specific elements of it.

A complete V diagram comprises twelve different elements, which all form parts of human knowledge construction (Figure 2).

Learning often starts from some kind of *question*. It can be a simple question, "Is that red fruit an apple?", or it can be a more complex question. We may have a strategy or make a plan how to find an answer to our question. The V in diagram points to the *events or objects* we will "investigate" to find the answer to our question.

The left-hand side of a complete V diagram, the conceptual/theoretical side, contains six different elements. A person's *world view* consists of her beliefs and values and forms the way she looks at phenomena and objects, what she is interested in and wants to learn more about (Novak, 1998, p. 83–86). It motivates her to pose questions and look for answers to her questions, and also influences how the results will be valued. *Philosophy* is used in the V-diagram in the sense of epistemology, i.e., our beliefs about the nature of knowledge and how it is created. *Theory* entails the principles that guide an investigation and *explain why* events and objects exhibit the way they do. *Principles* points to relationships between concepts and *explain how* events or objects can be expected to appear or behave. Finally, on the theoretical side we have *concepts.* They are defined by Novak as "perceived regularity in events or objects, or records of events or objects, designated by a label". The concepts help us to perceive regularities in the events or objects that we observe. They are the fundamentals in human knowledge construction (Mintzes & Novak, 2000, p. 51). In addition, the left-hand side of Gowin's V diagram contains *constructs*, which are conceptual creations that connect sets of concepts specifying regularities in events (Gowin & Alvarez, 2005).

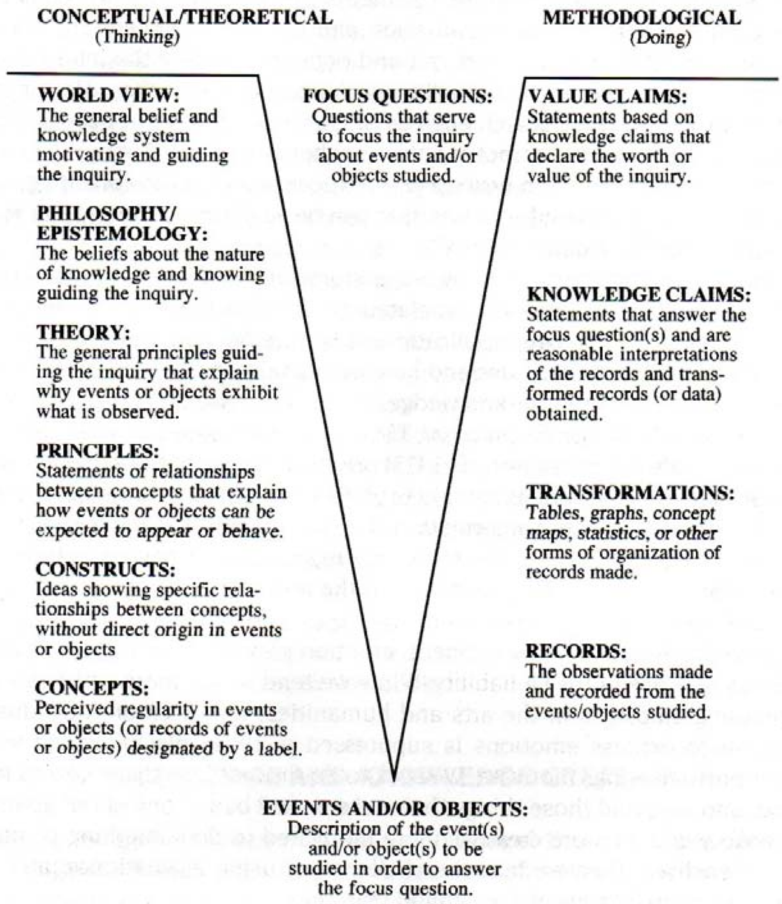


Figure 4.3: Gowin's knowledge-V [2]

The right-hand side of the V diagram, the methodological side, has its starting point down on the page at the element '*records*', which are descriptions of the observations made, for example measurements. What data records we choose to collect depend partly on our research question, partly on what concepts our observations are based on (Novak & Gowin, 1984, p. 60). To organize our data records we need to choose some kind of *transformation*, for example in the form of tables or graphs (Novak, 1998, p. 89). The transformations can be connected to the element "principles" on the left-hand side of the diagram. A table or a graph can show a relationship without explaining it. Based on our transformations we construct *knowledge claims*, i.e., conclusions that are answers to our focus/research question (Novak & Gowin, 1984, p. 62). Our claims build on our previous knowledge about concepts and principles. At the same time, our claims

[2] Novak, Mintzes & Wandersee, 1999, p. 10.

may entail that we construct new knowledge, i.e., we may deepen our understanding of a concept or give the concept a new meaning. The *value claims* constitute an affective component and answer questions such as, ”What is the use of this inquiry?”, ”Are the results positive or negative?” Our value claims depend on the theories, principles and concepts that form the basis for our inquiry, but also on the worldview and the philosophy on which it is based (Mintzes & Novak, 2000, p. 53).

Some research results

In her dissertation, Kurtén-Finnäs (2008) studied students in grade 7 working with open-ended investigations and V diagrams. The results show that for many of the students the work had a positive influence on their interest in chemistry and on their self-concept within chemistry. When working in groups with problem solving the students were able to develop their understanding of the problem and the concepts in question in dialogue with their peers and with the teacher. The open-ended investigations were occasions when the students could express their own beliefs. Students who had developed a deeper understanding of the problem had the opportunity to help others in the group. Many students experienced the thinking process as a characteristic and positive part of the investigation, and their own planning contributed to a feeling of ownership and agency. The V diagrams contributed to their understanding both in connection to the planning of the investigation itself and afterwards when revising for tests. Open-ended investigations supported by V diagrams can help students construct meaningful knowledge within chemistry education.

References

Aksela, M. & Juvonen. R. (1999). *Kemian opetus tänään.* Opetushsllitus. Moniste 27/99. Helsinki: Edita.

Bennett, J. (2003). *Teaching and Learning Science. A guide to resent research and its applications.* London: Continuum.

Berry, A., Mulhall, P., Gunstone, R. & Loughran, J. (1999). Helping Students Learn from Laboratory Work. *Australian Science Teacher’s Journal,* 45 (1), 27-31.

Clarke, D. (2001). Untangling Uncertainty, Negotiation and Intersubjectivity. In D. Clarke (Ed.), *Perspectives onPpractice and Meaning in Mathematics and Science Classroom.* Dordrecht: Kluwer Academic Press.

Cobb, P. (2000). Constructivism in Social Context. In L. P. Steffe (Ed.), *Constructivism in Action: Building on the pioneering work of Ernst von Glaserfeld.* London: Routledge Falmer. Retrieved April 29, 2008, from the World Wide Web: http://site.ebrary.com/

Cohen, E. G. (1994). *Designing Groupwork. Strategies for the Heterogeneous Classroom.* New York: Teachers College Press.

Crawford, B. A. (2000) Embracing the Essence of Inquiry: New roles for science teachers. *Journal of Research in Science Teaching,* 37 (9), 916-937.

Cronin-Jones, L. L. (1991) Science Teachers Beliefs and their Influence on Curriculum Implementation; Two case studies. *Journal of Research in Science Teaching,* 28 (3), 235-250.

Gardner, P. & Gauld, C. (1990). Labwork and Students' Attitudes. In E. Hegarty-Hazel (Ed.), *The Student Laboratory and the Science Curriculum.* London: Routledge.

Garnett, P. J., Garnett, P. J. & Hackling, M. W. (1995). Refocussing the Chemistry Lab: A case for laboratory-based investigations. *Australian Science Teachers Journal,* 41 (2), 26-32.

Glynn, S. M. & Duit, R. (1995). Learning Science Meaningfully: Constructing conceptual models. In S. M. Glynn & R. Duit (Eds.), *Learning Science in School. Research reforming practice.* Mahwah, NJ: Lawrence Erlbaum Associates.

Gott, R. and Mashiter, J. (1991). Practical Work in Science – a Task-based Approach? In B. E. Woolnough (Ed.), *Practical Science.* Buckingham: Open University Press.

Gott, R. & Duggan, S. (1995). *Investigative Work in the Science Curriculum.* Buckingham: Open University Press.

Gowin D. B. & Alvarez, M. C. (2005). *The Art of Education with V Diagrams.* New York: Cambridge University Press.

Hacklin M. W. & Fairbrother, R. W. (1996). Helping Students to do Open Investigations in Science. *Australian Science Teacher Journal,* 42 (4), 26-33.

Hodson, D. (1993). Re-thinking Old Ways: Towards a more critical approach to practical work in school science. *Studies in Science Education*, 22, 85-142.

Hodson, D. (1998). *Teaching and Learning Science. Towards a personalized approach.* Buckingham: Open University Press.

Hegarty-Hazel, E. (1990). Tertiary Laboratory Classroom. In E. Hegarty-Hazel (Ed.), *The Student Laboratory and the Science Curriculum.* London: Routledge.

Kurtén-Finnäs, B. (2000). Det laborativa arbetet i högstadiets kemiundervisning i Finland. In J. Sjöberg & S-E. Hansén (Eds.), *Kasvatus tulevaisuuteen. Pedagogik för framtiden.* Rapporter från Pedagogiska Fakulteten vid Åbo Akademi.

Kurtén-Finnäs, B. (2001). Studentkemi och laborativt arbete. *Dimensio* 65 (4), 44.48.

Kurtén-Finnäs, B. (2008). *Det var intressant, man måste tänka så mycket. Öppna laborationer och V-diagram i kemiundervisningen*. Available online from: https://oa.doria.fi/handle/10024/42561 (Diss.)

Lampiselkä, J., Savinainen, A. & Viiri, J. (2007). Teaching Methods in Science. In E. Pehkonen, M. Ahtee & J. Lavonen (Eds.), *How Finns learn Mathematics and Science.* Rotterdam: Sense Publishers.

Lunetta, V. N. (1998). The School Science Laboratory: Historical perspectives and contexts for contemporary teaching. In B. J. Fraser & K. G. Tobin (Eds.), *International Handbook of Science Education.* Dordrecht: Kluwer Academic Press.

Ministry of Education, (2004). *National Core Curriculum for Basic Education*, *2004*. Vammala: Vammalan Kirjapaino Oy.

Mintzes, J. J. & Novak, J. D. (2000). Assessing Science Understanding: The Epistemological Vee Diagram. In J. J. Mintzes, J. H. Wandersee & J. D. Novak (Eds.), *Assessing Science Understanding. A human constructivist view,* London: Academic Press.

Novak, J. D. (1998). The Interplay of Theory and Methodology. In E. Hegarty-Hazel (Ed.), *The Student Laboratory and the Science Curriculum.* London: Routledge.

Novak, J. D. & Gowin, D. B. (1984). *Learning how to learn.* Cambridge University Press.

Novak, J. D., Mintzes, J. J. & Wandersee, J. H. (1999). Learning, Teaching and Assessment: A human constructivist perspective. In J. J. Mintzes, J. H. Wandersee & J. D. Novak (Eds.), *Assessing Science Understanding. A human constructivist view.* London: Academic Press.

Roth, W-M. (1993). Metaphors and Conversational Analysis as Tools in Reflection on Teaching Practice: Two perspectives on teacher-student interactions in open-inquiry science. *Science Education,* 77 (4), 351-373.

Tamir, P. (1991). Practical Work in School Science: an analysis of current practice. In B. E. Woolnough (Ed.), *Practical Science.* Buckingham: Open University Press.

Trowbridge, J. E. & Wandersee, J. H. (1997). Theory-Driven Graphic Organizers. In J. J. Mintzes, J. H. Wandersee & J. D. Novak (Eds.), *Teaching Science Understanding. A human constructivist view.* London: Academic Press.

von Glaserfeld, E. (1993). Questions and Answers about Radical Constructivism. In K. Tobin (Ed.), *The Practice of Constructivism in Science Education.* Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers.

Wheatley, G. H. (1991). Constructivist Perspectives on Science and Mathematics Learning. *Science Education,* 75 (1), 9-21.

Wickman, P-O. (2002). Vad kan man lära sig av laborationerna? In H. Strömdahl (Ed.), *Kommunicera naturvetenskap i skolan – några forskningsresultat.* Lund: Studentlitteratur.

Guidelines for language support in chemistry education

These guidelines particularly concern the education of pupils with a first language other than the school language, but also that of mainstream pupils on their way towards mastering a more subject-specific and abstract academic language. A functional everyday language between pupils does not automatically ensure that they can answer to the demands of a more academic language that increase with each school year. For this process, a transmission model of teaching seldom provides the pupils with enough opportunities for testing, consolidating and developing their knowledge or their language within the specific genre of the school subject.

The use of open-ended investigations, on the other hand, is a good way of working for teachers who want to support the development of their pupils' language, thinking and knowledge simultaneously. Through the use of contextualized investigations there will be less pressure on language as the only means for understanding the content. At the same time the pupils' language development will be supported by the way the work process is contextualised, and by participating in a process which not only encourages but actually demands interaction for solving the problem!

The following pointers can help teachers to support their pupils' learning during different stages of the work in the chemistry classroom, both when making use of open-ended investigations and otherwise.

The important beginning: how can we activate and map the pupils' prior knowledge about the topic/theme?

We know that learning is supported when prior knowledge is activated. Also, learners create their own alternative assumptions about, and explanations of, phenomena, which they encounter in science, and which naturally influence their learning. It can therefore be very helpful to let the pupils put their assumptions into words, so that the teacher can take them into consideration in the educational process. For pupils with a minority cultural background, a theme can be almost, or totally, unknown, both subject-wise and concerning language and conceptual development. Preconceptions about phenomena such as how ice is formed on lakes and seas might not only differ between e.g. Nordic and North African children, they might be totally missing for the North African children. This means that the teacher needs to be even more careful that the topic is clearly contextualized. Also, the younger the learner and/or the more cognitively demanding the content, the more contextualization is needed to support the understanding.

Possibilities to consider at the beginning:

When planning: identify both key concepts and phrases/language functions that the pupils will need and check that they have been or will be dealt with accordingly. It is a good idea to write up both a list of concepts and a more general list of phrases to give to pupils at the beginning of a course, and to which they can add as required. It is also worth planning how to link back to existing support material in the instructions.

Check if you can provide the pupils with translations/explanations of key concepts into their mother tongue, preferably beforehand so that they have the possibility to prepare;

Introduce the topic with the use of visual contextualization, preferably using several different media, to support understanding and create interest;

let the pupils discuss and write down what they know about the topic and what they would like to know, in small groups: if need be, plans can be adjusted accordingly;

revise and emphasize key concepts in explanations, make use of body language and gestures, look for signals suggesting that additional explanations are needed;

Show how key concepts and phrases can be used and, at the same time, start building concept maps for the support of both language and content development, using a storable medium to be able to recapitulate and add on to later; the pupils also need to work on maps of their own to have support for their individual work; let concept maps and other support material be visible throughout the work process;

An alternative way is to first let the pupils experience a certain phenomenon and then provide them with the subject-specific concepts they will need to be able to discuss this phenomenon; if the pupils also get the opportunity to express their new insights in writing, they can develop an even more decontextualized subject-specific use of language than they use in their here-and-now discussions during investigations;

Labels on items to be used in an investigation can support beginners.

2. For work in small groups

Pupils can be grouped so that second language learners work with pupils that will be able to support the process, e.g. more advanced bilingual pupils or pupils that are capable of working inclusively in groups. Encourage majority pupils to describe their actions, even if what they do might seem self-evident, since this will help the second language pupils to put words on what is happening in the classroom.

3. Work outline: possibilities for supported dialogue

Encourage interaction and make pupils aware of its importance for learning! Support them by providing the opportunity to express themselves both orally and in writing at regular intervals around specific concepts and themes. This will not only help them consolidate concepts, but also provide guidance for the aspects of language and thinking that need to be further supported.

The possibility to first hear subject-specific language being used and then also try it out in smaller group settings encourages interactional use and thus supports learning. Ensure that the pupils are also able to discuss directly with the teacher throughout the work process. This enables the pupils to get responses, both explicitly and implicitly, on the way they make use of new concepts. The teacher can make conscious and explicit use of new concepts, i.e. “talk chemistry”, particularly if the pupils try to avoid them in their questions and discussions.

Also, provide the pupils with continuous linguistic models for how they can formulate themselves, both orally and in writing, in a way that is acceptable for both genre and level not only considering concepts but also e.g. problem formulation, testing of hypotheses and presentation of results. For most pupils, this type of cognitively demanding academic language does not develop on its own. The use of V diagrams in open-ended investigations can support the academic language development of the pupils through its clear work structure and the way it promotes the use of new concepts throughout the work process. In addition, relevant concepts are made visible by constituting a separate field in the structure of the diagram.

Note that small, common words that tie texts together to express relations such as cause and effect can be difficult to understand (e.g. despite; thereafter). Also words that mean different things in different contexts and idioms (e.g. to be at odds; better safe than sorry) can be problematic, but through rephrasing or definitions their meaning can be clarified.

Refer to concept maps and other support structures, e.g. when the pupils have questions or when it is time to report on work processes and results. This will also make them more conscious of strategies for autonomous learning.

Also provide feedback on the end product concerning the language of the specific genre, both relating to subject-specific concepts and specific formulations to be used e.g. in reports. Common challenging issues can be processed in whole-class discussions for example in the form of focus areas without being attributed to certain individuals or groups.

4. Time to think

A few seconds of extra time to think during discussions can be of great help for those who have to express themselves about a new topic in a new language! The class needs to learn to respect this.

5. Last but not least

Show that you like working with the pupils and that you will support their learning because you want to, and because it is possible!
If pupils perceive that their presence in the classroom creates extra problems for the teacher, they will feel less good about themselves and learn less. Try finding ways of regularly involving the specific background knowledge of each pupil to show that they are all assets to the class, at the same time as their learning is being supported.

Examples of key concepts for different stages of an investigation (in alphabetical order):

analysis – to analyze an argument – to argue a cause –> an effect a conclusion – to conclude = to draw a conclusion from data
diagram evidence – to prove an exploration - to explore an experiment – to experiment with a hypothesis - to hypothesize an observation - to observe a prediction – to predict a report – to report

Examples of concepts with differing meanings in everyday language and in science:

A pure substance = in everyday language this tends to mean something that is ”safe” or ”non-toxic”, but in chemistry it means that the substance is made up of only one type of particles. Examples: gold, oxygen, calcium (they are elements); carbon dioxide, sodium chloride (which are compounds).

A salt, many salts = means ”cooking salt” or ”table salt” in everyday language, but in chemistry it is an umbrella term for a number of compounds, e.g. monosodium glutamate and ammonium nitrate are two different salts.

To dissolve = in everyday language we say that ”sugar melts in coffee”, but in chemistry we need to say that sugar dissolves in coffee.

A solution = in chemistry, a solution is a homogeneous mixture composed of two or more substances. In such a mixture, one substance (called a solute) is dissolved in another substance (known as a solvent).

Examples of what could be included in a list of phrases:

Our hypothesis is that... The experiment shows that... What conclusions can be drawn? The conclusion is that...
The [more] ..., the [more]... For example: The higher the degree of salt, the more slowly it dissolves in the liquid.

Dilute: introduction[3]

The teacher introduces a very relevant concept for the investigation: dilute. She uses direct translation into Swedish (“späda ut”) and Finnish (“laimentaa”), in addition to a definition in English: You add water so it’s not as acidic anymore.

Defining consecutive

Here the teacher is making use of visual contextualization of the pH scale, as well as pointing at the intervals on the scale. In the discussion, the word consecutive comes up in connection to the intervals of the pH units. As the teacher suspects it to be an unfamiliar word, she adds a definition to her visual explanations: Consecutive means

[3] This section should be used in conjunction with the video material.

"that come after each other".

The pH scale

Here the teacher is making use of visual contextualization of the pH scale, as well as pointing at the intervals on the scale. In the discussion, the word "consecutive" comes up in connection to the intervals of the pH units. As the teacher suspects it to be an unfamiliar word, she adds a definition to her visual explanations: Consecutive means "that come after each other".

Red cabbage water

Since red cabbage water is going to be used as indicator in the investigation, the teacher concretizes the discussion by putting slices of red cabbage in water to boil.

Diluting red cabbage water

In the beginning of the lab lesson itself, the teacher revises the concept of diluting concretely by diluting the red cabbage indicator with water: And be careful now that you don't just get the effect of diluting, which means that if you have your indicator and you have a certain colour of the indicator - now I do this with regular tap water – you see when you put water in it, it will turn lighter purple, but this is now just because it is more diluted, "utspätt", "laimennettu". We want to have different colors, this is not a different color than what I had before, this is just more dilute.

Dilute: introduction

The teacher introduces a very relevant concept for the investigation: dilute. She uses direct translation into Swedish ("späda ut") and Finnish ("laimentaa"), in addition to a definition in English: You add water so it's not as acidic anymore.

Dilute: revision

The concept dilute and its relevance for the investigation is revised: Dilute, "späda ut", "laimentaa".

Dilute: adding inflected forms

At the beginning of the lab lesson itself, the teacher revises the concept of diluting concretely by diluting the red cabbage indicator with water. Again she provides the translations into Swedish and Finnish, but this time she also uses the past participle in all three languages: And be careful now that you don't just get the effect of diluting, which means that if you have your indicator and you have a certain color of the indicator

- now I do this with regular tap water – you see when you put water in it, it will turn lighter purple, but this is now just because it is more diluted, “utspätt”, “laimennettu”. We want to have different colors, this is not a different color to what I had before, this is just more dilute.

Hydrochloric acid

In the beginning of the lab lesson itself, the teacher gives the Swedish and Finnish words for hydrochloric acid: Hydrochloric acid, HCl, “saltsyra”, “suolahappo”, hydrochloric acid.
Transmission models of teaching, where the pupils mainly listen and read about new concepts without actively and repeatedly using them, are not enough to support the linguistic and conceptual development of most pupils.

Here are two examples of how opportunities for interaction can result in the learning of new concepts: **Benzoic acid; Dilute**.

In videoclip 3, "Pupils [students] planning their investigations", we see how the pupils integrate benzoic acid into their vocabulary through a clear progression. Initially they avoid trying out the concept and refer to benzoic acid as ”that- that thing”. Next they misuse the concept, calling it ”the ben- benny acid”. After that they move on to a correct but still repeatedly marked use of the concept that suggests that it is still new knowledge that might need to be further processed before becoming completely integrated into the pupils’ vocabulary, e.g. ”acid, be- benzoic acid”; ”that benzoic acid”.

S1: So if we first add water.
S2: I don’t know, would that work?
S1: Yeah yeah, the salt disappears in the water, then we sieve it through-
S2: The salt disappears in the water.
S1: What-
S2: Salt disappears in water, right? Dissolves- salt dissolves in water.
S1: Mm
S2: That- that thing doesn’t dissolve in water.
S1: The ben- benny acid, yes.
S2: Yes. And sand is still pretty visible in water. So if we sieve the water away, shouldn’t we then have the salt or that-

S1: The salt and the sand are left.
S2: Yes no or that acid we get.
S1: Then we have-
S2: Then we- S1: Then we have the salt in the water. Then we have the salt in one place!
S2: Yes. But I don't know if that would work. It seems- it seems too simple.
S1: But it's not the whole thing, we still have to separate sand and- and...
S2: Acid, be- benzoic acid.
S1: Right. So how do we do that then?
S2: It dissolves in the water.
S1: Mm
S2: So, we put in water.
S1: Yes w-a-t-e-r, okay, but how can we separate?
S2: But then we take it away by sieving, so what's left is sand and that- that...
S1: Yeah, one is white and one is brown. I think X wants to like pick by hand, everything white and everything brown in one pile.
S2: No, but that's sort of- that's not possible.
S1: Yes.
S2: But what about- it doesn't say that we-
S1: Do we have any special like properties for this...
S2: Benzoic acid... we have to see... Benzoic acid.
S1: Well, hardly specifically for that, just find some acid.
S2: Is there a register at the back... here we have- no.
S1: Okay, we put everything in water, mix and we take the salt away, we sieve it so sand and...benzoic acid are left, then we put it in water again and boil it so we have the sand left.
S2: Yes, that seems reasonable, because it should disappear or does it, we don't know that. But it has to disappear faster than the sand, hasn't it? It's not that easy to boil sand.
S1: Because sand is quartz it seems.
S2: Yes, and it's not really possible to boil stone just like that.
S1: Here we have benzoic acid.
S2: Did you find it?

S1: The melting point is-

S2: 122, that's possible to reach with a gas burner.

S1: Yes, but then it melts, so it'll be left in the water.

S2: Does it melt? Yes, then we see where the sand is.

S1: Yes.

S2: Yes, it doesn't boil until 249, yes.

S1: So then we sieve it-

S2: Then we won't put it in water, we simply put it on the burner- or why should we put in water since it will melt anyway? Surely we'll be able to see which one has melted.

S1: Since we'll have sand left and... that in one of those small things, we'll put it on a burner. Yes, here it is. The whole thing looks like ordinary sand.

S2: Yes. Yes, that seems reasonable, the salt will remain here. This is what we'll do: first we add water here so the salt dissolves, sieve it so the salt is left in another one of these and we have sand and that benzoic acid left in this. Then we put it on a gas burner and heat it up to 122 degrees, then this benzoic acid should melt and the sand is left. At least we'll be able to see it.

S1: Then there'll be a liquid left, yes. And then we sieve it through so we have the sand and the benzoic acid separately. Does that sound okay?

S2: That's what we could try to do.

Before looking at the examples of language support in the clips below, it should be noted that the pupils in this pre-IB group are either Swedish or Finnish (or bilingual in Swedish and Finnish) pupils who are working in a foreign language (English). Because they all share the experience of using a language other than their mother tongue, their situation is somewhat different from that of e.g. immigrant pupils constituting the minority in a group using the majority language. For example, in this case the teacher is able to provide the pupils with translations of certain concepts, and it is easier to adapt to the level of the pupils more as a group. Their level of English is also advanced enough for studying the subject at this level, although the pupils probably speak less than they would if they were using their mother tongue (or if they were not being filmed!).

Still, the importance of providing interactional opportunities for successful language learning to occur applies to all contexts! Compared with much of the use of communicative activities in foreign language learning classrooms, these pupils actually have an authentic purpose for their interaction: to agree on and follow through a work plan for their investigation!

Dilute: introduction

In the introductory lesson the teacher introduces the concept of dilute. She uses direct translation into Swedish (“späda ut”) and Finnish (“laimentaa”). She also provides an English definition: You add water so it’s not as acidic anymore.

Dilute: revision

A bit later the same lesson the concept and its relevance for the investigation is revised, again with translations into Swedish and Finnish. At the same time the pupils get another chance to react to the content: Does it make sense?

Dilute: adding inflected forms

In the beginning of the lab lesson itself, the teacher revises the concept concretely by diluting the red cabbage indicator with water. Again she provides the translations into Swedish and Finnish, but this time she also uses the past participle in all three languages: And be careful now that you don’t just get the effect of diluting, which means that if you have your indicator and you have a certain color of the indicator - now I do this with regular tap water – you see when you put water in it, it will turn lighter purple, but this is now just because it is more diluted, “utspätt”, “laimennettu”. We want to have different colors, this is not a different color than what I had before, this is just more dilute.

Using the concept in interaction

This clip shows how the pupils in one of the groups use the concept dilute during their investigation. The way the sentence is uttered suggests that the pupil is in fact trying out an unfamiliar concept: there is confusion of sentence structure, a slight pause of hesitation in front of "diluted", and the pronunciation of "diluted" differs from that of the teacher.

Transcript

S1: We can say this is yellow, because this is kind of yellow.

S2: But that’s not yellow, that’s more like lime green.

S3: Yeah

S1: Yeah, but that what's the teacher (was) saying, it's still like the same but- diluted in different ways.

S2: [adds some drops] Now it's dark green.

S1: It's still green!

S2: Yeah, but it doesn't matter, it's like a different color than the first one

S3: The first one is like more yellow green.

S2: Yeah, we can just put like lime green.

S1: OK.

Avoiding the concept

As the teacher moves around between the groups, they get the chance to discuss their ideas with her, and at the same time they can get feedback, explicit or implicit, on their use of concepts. A way to try to ensure the practice of key phrases is to make explicit use of them in these discussions, to "talk chemistry", even if the pupils try to avoid the concepts in their questions. In this clip, one of the groups avoids using the concept during their planning despite a discussion where it would be appropriate: We could put water in one so it blends into something lighter.

Using the concept after interacting with the teacher

In the final clip it is possible to hear the group in the background use the concept immediately after a discussion with the teacher where she also uses the concept:

> T: The main thing is that you know what you are doing, how much more you're diluting it so you can then write it down in your recipe. Because it is possible to get all the different colours. S: Oh, let's not dilute it (x) times (...)

Examples of literature on how to support the learning of pupils with a first language other than the school language:

Carrasquillo, A. & Rodríguez, V. (2002) *Language Minority Pupils in the Mainstream Classroom (2nd ed.*), Clevedon, Multilingual Matters

Coelho, E. (1998) *Teaching and Learning in Multicultural Schools*, Clevedon, Multilingual Matters.

Cummins, J. (2000) *Language, Power and Pedagogy. Bilingual Children in the Crossfire*, Clevedon, Multilingual Matters.

Gibbons, P. (2006) *Stärk språket. Stärk lärandet. Språk- och kunskapsutvecklande arbetssätt för och med andraspråkselever i klassrummet*, Uppsala, Hallgren & Fallgren Studieförlag AB.

Hajer, M. (2000) "Creating a language promoting classroom: content-area teachers at work", In J. K. Hall & L. S. Verplaetse (Eds.), *Second and foreign language learning through classroom interaction* (pp. 265-286). Mahwah, NJ, Lawrence Erlbaum.

Ladberg, G. (2000) *Skolans språk och barnets - att undervisa barn från språkliga minoritete*r, Lund: Pupillitteratur.

S-TEAM Product 6.12: The Role of the University in MST Education in Schools

Peter van Marion with Zozan Kaya Asphaug

Norwegian University of Science and Technology (NTNU)

Preface: This report aims to provide an in-depth analysis of the challenges related to school-university collaboration in science education, and addresses the requirements of product 6.12 of S-TEAM. It consists of three parts. Part one discusses the challenges in Teacher Professional Development (TPD) in school science. The second part describes how the Resource Centre at the Norwegian University of Science and Technology (NTNU) has met these challenges. The final part offers recommendations for school - university interaction and collaboration in the field of in-service training and other activities aiming at improving the quality of Mathematics, Science and Technology (MST) teaching in schools. These recommendations were formed by the participants at a two day seminar held April 8-9th 2010 in Trondheim, Norway. In addition to representatives from one of NTNU's partner institutions, Mälardalen University of Sweden, the seminar participants were from Physics and PLU at NTNU as well as staff members from the Research Centre.

Introduction

The literature suggests that the preparation and continuing professional development of teachers in mathematics, science and technology (MST) requires a more systematic approach (Osborne & Dillon, 2008). However, whilst there is agreement that science education is important for all school pupils, there has been a lack of debate about its nature and structure, resulting in ambiguity about the purposes and goals of formal science education across Europe (ibid, p.20).

This report will discuss some of the challenges facing MST education (MSTE), specifically those challenges encountered by universities seeking to improve school-university collaboration in science. A recurring question concerns the extent to which universities should interact and collaborate in MSTE in primary and secondary schools. As this paper is concerned with teacher development in MSTE in a broad sense, the term 'teacher professional development' (TPD) is preferred to "teacher learning".

Our first objective is to look at the challenges related to the interaction between the academic world, on the one hand, and the everyday school world on the other. How do universities face these challenges and help advance MSTE in schools? What roles should universities actually play in MSTE?

Our second aim is to describe some of the steps that the Resource Centre for Mathematics, Science and Technology Education at NTNU has undertaken in order to face these challenges and some of the resulting outcomes. The case of the Resource Centre will serve as a model for school - university interaction and collaboration in the field of in-service training and other activities aiming at improving the quality of MST teaching in schools. The Resource Centre is an interesting case, because it forms the link between the university and schools, and is intended to facilitate a more efficient communication between scientists and MST teachers in schools. Indeed, since its establishment in 1999, the Centre has played a key role as a promoter of MST in schools and, as such, has tried to bridge the gap between MST in a traditional academic context at university and MST in a school context (Van Marion 2009, p.1). The case study therefore, serves as a good point of reference from which to discuss the role of universities in MST education in school and to form recommendations.

The challenges in TPD in school science: Need for more Innovative Curricula

A glance at the academic literature suggests that there seems to be common international concern about a general lack of expertise in MSTE. Indeed, there are many challenges related to school science education. In their critical analysis of science education in Europe, Osborne & Dillon (2008) argue that traditional curricula in school suffer from a number of difficulties. The main problem, they claim, is that curricula have been determined by scientists, who perceive school science as basic preparation for a science degree. While this strategy may cover basic knowledge, it is still simply a "short cut". In this view, both the content and pedagogy of MSTE fail to encourage pupils to continue with science studies. The authors' contention is that such an education fails to meet the needs of the majority of the pupils who require a broad overview of the key ideas that science offers, how it produces reliable knowledge, and the limits to certainty (Osborne & Dillon, 2008, p.7). In turn, this leads to reduced motivation for MST amongst pupils.

Recruitment to MST remains a Significant Challenge

In addition, there is concern that most western countries are experiencing a noticeable decline in recruitment of pupils to various MST programmes (Norwegian Ministry of Education and Research, 2010-2014). According to an OECD report, trends indicate declining enrolments in the science and technology fields (OECD, 2006). The case of Norway arguably illustrates this point. The number of applicants to programmes of study in MST is not satisfactory. From 2004-2005, there was a decline in these applications of 16.6 percent, even if admission to these programmes in general is fairly easy. As a result, the number of graduates in these areas also remains low (Norwegian Strategy 2006-2009, p.13).

Further, according to the UN *Index of Human Development*,[4] Norway is top of the list of countries in which pupils have the most negative attitudes towards science.

Trends, however, are not static and the situation may be improving. Over the period 2005-2009, there has been an increase in the number of applicants to MST courses. In mathematical disciplines, there has been an increase of 12.6 per cent for first priority applicants and in technology there has been an increase of 30 per cent over the same period. There is still a long way to go in order to reach OECD average levels, and

[4] http://hdr.undp.org/en/statistics.

recruitment thus remains one of the main challenges in Norway (Norwegian Ministry of Education and Research, 2010-2014).

Another challenge is an enduring problem with under-representation of female MST pupils (Van Marion, 2009; Osborne & Dillon, 2008). This problem exists throughout the Western world. The percentage of females graduating from MST subjects has remained at about 25 per cent the last ten years (Norwegian Ministry of Education and Research, 2006-2009). This gap between girls' and boys' interest in MST in turn raises questions about how curricula can be made more innovative and encouraging for girls' engagement and motivation.

Declining Student Performance in MST

The level of MST achievement in many European countries continues to be poor, according to numerous surveys. Whereas the OECD *Programme for International Student Assessment* (PISA) measures 15-year-olds' literacy in reading, mathematics and science, the *Trends in International Mathematics and Science Study advanced survey* (TIMSS) assesses pupils of school-leaving age with special preparation in advanced mathematics and physics. The science scores for European countries measured in PISA 2006 show that Finland is the top performer in science, but many other European countries are low in the rankings compared to Asian countries such as Japan and Korea,[5] which were among the top ranked countries in a study measuring 265,000 15-year-olds' competencies in reading, mathematics and science.[6]

The comparative performance of Norwegian pupils in mathematics and natural sciences has become gradually weaker. Even if there has been an increase in MST recruitment in higher education in 2009 (Norwegian Strategy 2010-2014, p.22), Norwegian pupils have the lowest score of all the Nordic countries, and are ranked below the OECD average in both PISA and the TIMSS Advanced Survey.

As regards sciences, the PISA results from 2006 show that only 6.1 per cent of Norwegian pupils perform at levels 5 or 6 (high performers) against an average of 9 per cent for the OECD countries. Similarly, in the TIMSS Advanced Survey, where 10 countries participated, Norwegian pupils' achievement in advanced mathematics was

[5] http://ourtimes.wordpress.com/2008/04/10/oecd-education-rankings/)

[6] www.oecd.org

significantly below average. Moreover, Norway is one of the countries with the greatest gender imbalance of pupils taking advanced courses in mathematics.[7] As the PISA study concludes; the Norwegian results are definitely worrying. [8]

This scenario not only affects recruitment, but can, in a wider perspective, also be linked to the functioning and development of modern societies more generally. Grossman et al (2001. p.81) describe public schools as "cornerstones of democracy", charged with instilling in future citizens the skills and sensibilities required to participate in public life, and therefore vital to sustaining a thoughtful, engaged, and vigorous democratic society.

Indeed, it could be argued that citizens of a modern society need MST competence in order to participate in democratic processes. According to the *Norwegian National Strategy Plan for Promotion of MST*, "our future and progress in the international society are dependent on a high level of MST competence". MST competence is stated to be of great importance in order to coordinate private economic affairs, to be able to participate in the public debate on significant issues such as gene technology, or even form an opinion on economic or social matters (Norwegian Ministry of Education and Research 2006-2009).

The PISA study does not provide simple reasons for better perfomance by nations such as Finland, Japan and Korea (Norwegian Strategy 2010-2014, p.15). Rather, "successful performance is attributable to a constellation of factors," according to OECD Deputy Director for Education, Barry McGaw. PISA is based on a clearly defined framework of scientific literacy that undoubtedly covers important aspects of science education but should in no way be regarded as comprehensive and the only benchmark criterion (S-TEAM, 2010, p.2).

Countries vary not just in how much they spend on education, but also in how they spend their money.[9] This may also affect the performance of countries in education in science. For example, since the Norwegian Government began an initiative to promote MST, there have been significant improvements for 4th graders in mathematics and science between 2003 and 2007, according to a TIMMS study. This suggests that the negative trend might be reversing.

---

[7] http://www.iea.nl/timssadvanced20080.html

[8] http://www.pisa.no/english/index.html

[9] http://www.oecd.org/dataoecd/1/28/43654482.pdf

School-University Collaboration in Science

What, then, is the role of universities in addressing these challenges? And why should universities collaborate more closely with schools to solve these problems?

In addition to overcoming the challenges facing MST, the literature adds the following reasons why universities should engage in MST teaching in primary and secondary schools. Firstly, children normally develop their attitudes towards MST at a young age. Despite the influence of parents, the media and personal experience, the key factor appears to be teaching and learning in lower grades at school. Hence, good quality teaching practices in primary and lower secondary school are essential. Accordingly, universities' active involvement in TPD for primary and secondary education may lead indirectly to stronger recruitment of pupils to MST subjects.

Secondly, if universities engage directly in primary and secondary education, they can take preventative steps towards tackling pupils' declining performance in MST at an early stage. This, in turn, may improve the quality of teaching and subsequently the levels of MST knowledge for pupils entering tertiary education (Van Marion 2009).

How can Universities do this?

University staff in teacher education may work as mentors, teaching and guiding school teachers, who in turn instruct pupils. Equally, scientists have a unique capacity by virtue of their specific expertise in MST topic areas. When mathematics and science teachers gain knowledge through direct contacts with scientists at university, it can create a new awareness of the relevance of research and development and inspire teachers to teach mathematics, natural sciences and technology differently. Scientists in universities can not only offer hands-on experiences of what MST is actually about, but are also able to communicate to young people exactly how important knowledge of MST is for a society as a whole. They can enhance curiosity and motivation regarding mathematics, science and technology at school and at home. Furthermore, university staff can contribute to the development of curricula, new teaching materials and teaching methods, and actively follow up these with the teachers involved.

One specific possibility could be to invite school classes to visit universities to learn about what studying mathematics, natural sciences or engineering are really about, to learn about possible future career opportunities and learn about the impact of scientific research in modern society. As such, pupils will get a unique chance to familiarize themselves with new and sometimes spectacular sides of science and technology. Indeed, through hands-on experience, and by learning to see MST as something exciting, pupils may be able to relate it more to their own lives and to society as a whole.

A major challenge in the collaboration between university and school is that there is need for a ‘broker’ or facilitator. Several studies suggest that the facilitator is crucial to the success of professional development programmes (Borko, 2008, p.10). The Research Centre embodies this role of communicating the needs of school science teachers to experts in the university. This avoids the miscommunication that may occur when university professors and school teachers “speak different languages”. As Van Marion has shown, their fundamentally different cultures make communication problematic as “they can’t relate to each others’ worlds” (Van Marion 2009, p.3). Van Marion has observed that university professors, in charge of in-service courses for science teachers, do not necessarily stimulate desirable responses or the enthusiasm of the teachers. In this context the Resource Centre is intended to decrease the gap between the university professors’ perception of the needs of science teachers and the science teachers’ own perceptions.

The following section elaborates these activities and their potential effects by presenting a case study of NTNU’s Resource Centre in further detail.

The Challenges of MST in Norway

The decline in the numbers of pupils enrolling in MST studies, coupled with a decline in student attitudes to science, is apparent in a global context as well as amongst universities within Norway. For the EU it poses a threat to the Lisbon agenda, which aims to place the EU at the forefront of the knowledge economy of the future (Osborne & Dillon, 2008, p.11). There are several reports that map the shortcomings of science education in Europe and also suggest some attempted solutions and remedies. They all, albeit to various degree, emphasize that teacher professional development is essential to improving school performance in MSTE (Borko, 2008; Osborne & Dillon, 2008; Fishman et al, 2003). According to Borko, teacher development occurs across many different aspects of practice, including the classroom, school communities, and professional development courses or workshops (Borko, 2004, p.4). Nevertheless, European countries still lack knowledge and evidence concerning the efficiency of both traditional approaches and of new models for TPD (S-TEAM 2010, p.4).

In Norway, there is a common understanding that changes are needed both in national curricula, and in the way that science teachers are educated. For example, the OECD's Economic Review from 2007 suggests that Norway should strengthen teachers' pedagogic knowledge and skills in MST.[10]

Another study, the OECD's Teaching and Learning International Survey (TALIS) gives a comparative perspective on the conditions of teaching and learning (OECD, 2009). TALIS highlights better and more targeted professional development as an important lever towards improvement. Currently, relatively few teachers participate in the kinds of professional development with most impact on their work, namely qualification programmes and individual and collaborative research. For instance, 2008-2009 results show that as many as 70 per cent of Norwegian teachers want more hours of professional development than they receive.[11] In light of these facts, many countries have therefore decided to augment their teacher training by providing more teacher professional development (TPD) activities.

As a consequence of Norway's low ranking in international surveys, the Norwegian Government has launched two Strategic Plans for the Promotion of Mathematics, Science and Technology (Norwegian Ministry of Education and Research, 2006; 2010-2014). These national strategies call for measures to enhance young peoples' attitudes towards MST. This is however a long term process, and as stated, broad efforts must be made, from kindergarten to research and working life in order to improve competence and increase recruitment to MST careers (Norwegian Ministry of Education and Research, 2006-2009).

Whereas the first strategy called for a renewal of the content of MST in the curriculum, and improvement of MST competence across the whole education system, (Norwegian Ministry of Education and Research, 2006-2009), the second emphasizes that pupils in primary and secondary education should be taught by highly qualified MST teachers, meaning that "teachers should have sufficient professional knowledge within the subjects they teach and they should have the pedagogic knowledge and skills that enables them to inspire and motivate their pupils" (Norwegian Ministry of Education and Research 2010-2014, p.17). Other main goals are to increase recruitment, especially of females, as well as to improve pupils' performance and attitudes towards MST.

[10] http://www.oecd.org

[11] http://www.oecd.org/document/54/0,3343,en_2649_39263231_42980662_1_1_1_1,00.html

In order to implement these strategies, the Norwegian Ministry of Education and Research has suggested various changes. Through the implementation of a new national curriculum, the content of mathematics and science in school has been renewed. A major goal for this renewal has been that the learners should perceive the content of these subjects as relevant. In this sense, curriculum is a key factor in instilling more positive attitudes towards MST among pupils and the public in general.

Another key factor is the creation of better programmes of professional development. It is essential to focus on how teachers in MST teach content and how they organize the work. Some of the activities initiated to advance MST are short-term measures, such as in-service training to improve teachers' subject knowledge. A more long-term initiative will be the recruitment of students who want to specialize in MST to teacher training (Norwegian Ministry of Education and Research 206-2009, p.9).

As of 2009, TPD courses have been increasingly subsidized, in fact, the Norwegian Government has granted 117 million NOK to TPD measures in 2009, and is planning to increase this amount to 312 million NOK per year when the system of TPD is at full capacity (S-Team 2010, p.52).

This development is arguably a step in the right direction, notwithstanding the difficulties of providing empirical evidence that the goals as set out in the national strategy for MST will actually be met. It is also relevant for the Norwegian University of Science and Technology's *Resource Centre for Mathematics, Science and Technology Education* whose main purpose relates to how teachers teach.

The next section will look more specifically at how NTNU provides solutions to the major challenges identified in the national strategy, and our recommendations based on the Centre's experiences.

TPD at the Resource Centre

Traditional approaches to TPD often follow a top-down strategy, including workshops, train-the-trainer, and speaker series, and have relied primarily on transmitting new ideas of teaching and learning through hierarchical structures (Ruopp & Haavind, 1993). Current practices of TPD acknowledge that professional development is about teacher learning where teachers become members of a community of learners (S-TEAM, 2010, p.4). These alternative forms of TPD adopt a structure that is predominantly informal, occurs in context (Schlager, Fusco, & Schank, 2002), and involves ‘‘consultation, problem-solving, and programme development’’ (Little, 2001, p.23).

From a theoretical perspective, this is in line with social constructivist thinking about pedagogical practices. According to this view, it is changes in the knowledge, beliefs and attitudes of teachers that lead to the acquisition of new skills, new concepts and new processes related to the work of teaching (Fishman et al 2003, p.645). Further, the development of a group identity, teacher communities and the formulation of a sense of communal responsibility for the regulation of norms and behaviour may foster teacher learning and potentially have an effect on pupils, even though measuring knowledge is difficult (Borko, 2008).

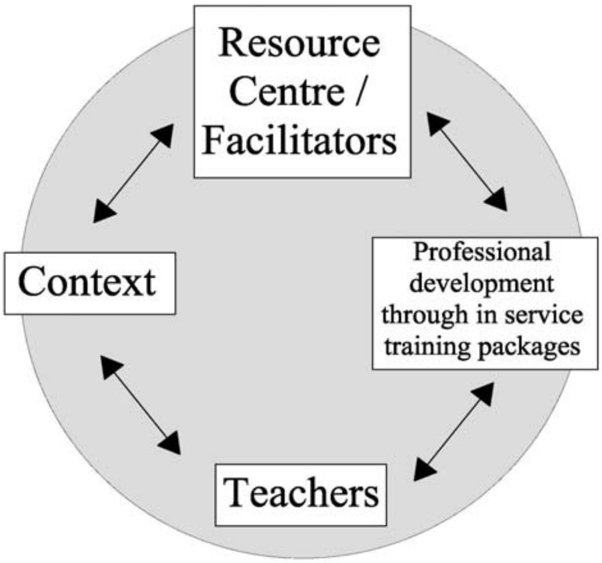
Building upon the social constructivist perspective, every learning experience, rather than being something static, is seen as context-bound, and thus continuously changing according to content, strategies and modes of delivery (Fishman et al, 2003). For example, pedagogical approaches (strategies) may include planning assistance, examination of student work, guided 'tours' of curriculum materials and hands-on experiences with technological tools, amongst others (Fishman et al, 2003). The mode of delivery may also vary according to the context. As Fishman puts it, each “site or context” lends itself to particular strategies and media. Traditional contexts for teacher learning include after-school sessions, summer workshops, or graduate-level coursework related to teachers’ own interests. Other, more modern methods may include teachers learning through on-line professional development, or through reading professional journals and other educational materials.

NTNU’s role in School University Collaboration in Science Education

The Norwegian University of Science and Technology’s *Resource Centre for Mathematics, Science and Technology Education* was established to address problematic trends in science education as outlined above. The Resource Centre is situated at the crossroads between professional teaching practice in schools, and research in science and technology, and forms a meeting place for science teachers and scientists at the university. The Centre’s main goal has been to improve teaching practices in MST in primary and secondary education. In particular, the Resource Centre adheres to two specific approaches, namely to raise the MST qualification of teachers in schools through in-service training, and secondly, to improve the quality of teaching in

MST through the development and dissemination of new teaching materials and practices. Teacher learning at the Resource Centre thus occurs within multiple contexts and along the lines of Borko's understanding of teacher learning; by taking into account both the individual teacher-learners and the social systems in which they are participants (Borko 2004, p.4).

Fig.1: Model of Teacher Learning/School – University Collaboration in Science Education



.

This simplified model shows some of the elements of a professional development system. It suggests that the Resource Centre has developed a model for TPD in which the Centre undertakes the facilitator and consultant role in the process, initiating various activities through in-service training packages, creating networks and communities, all aimed at creating better learning outcomes for pupils. Teacher development is in other words a process that occurs within multiple contexts; it is an affiliation between facilitators, the in-service courses of the Resource Centre, teachers as learners, pupils and context.

More specifically, the role of the Resource Centre is to initiate and to develop in-service training packages that are relevant to the needs of schools. This means that the

Resource Centre has to find and engage the right experts at the university who can contribute within their fields. Secondly, they need to create coherent courses that meet the needs of the participants, and, finally, they take care of all the practical matters that arise when an in-service training course for teachers is organized. Staff at the Resource Centre serve, therefore, as consultants for the university experts who are engaged to teach in the courses. Through dialogue, they give advice on how to approach the teachers, on the school curricula, on laboratory facilities in schools, on the prior knowledge of the teachers and in actively helping and supporting its participants in trying new ideas. Furthermore, staff members of the Resource Centre contribute their knowledge of teaching methods in school.

Yet, there are also some limitations. There are only three permanent staff members at the Resource Centre. Moreover, the expertise of the Resource Centre's permanent staff only covers specific subjects or areas within the fields of mathematics, science and technology and they depend on the expertise held by university scientists within specific fields.

In addition to the permanent staff, one staff member is employed by the Department of Teacher Training at NTNU and another half-time staff member is a science teacher from a secondary school. The latter, whose salary is paid for by the Province, is seconded for a two-year period, after which he or she is replaced by another teacher. Additionally, several teachers working on science or technology projects with external funding are based at the Resource Centre.

Professional Development

As noted earlier, The Resource Centre's main understanding of TPD is that there is continuous professional development of each and every MST teacher in schools. The section that follows examines the various initiatives and in-service courses in more depth.

In-service courses facilitated by the Resource Centre may cover short courses of one or two days length, or longer courses, usually 2 + 2 + 2 (3) days, where the participating teachers are given the opportunity to carry out development work in their own classes and do assignment work in the periods between the course days at university. The longer courses usually include a final exam.

Table 1. Examples of courses

Short courses	Longer courses
The universe	Biotechnology
Modern physics	Energy for the future
Digital tools in mathematics	Basic chemistry for lower secondary school
Experiments in physics and chemistry	Technology and research
Sustainable nuclear power	Technology and entrepreneurship
Biodiversity – fieldwork	Physics for upper-secondary school
	Chemistry for upper-secondary school

Most of the courses normally take place at the university, using the laboratory facilities at the Resource Centre or at the collaborating university departments. More recently the Resource Centre has initiated the development of an alternative model for professional development of teachers, in which groups of maths or science teachers at one particular school are offered a school-based programme, largely based on specific needs expressed by the participating teachers. This approach is largely based on a dialogue between the teachers and the Resource Centre and may be seen as a more tailor-made alternative to courses at the university, in collaboration with teachers from other schools. This is a promising but expensive model, for which funding may be scarce.

Workshops for Teachers and their Pupils

Whilst practical work is vital in MST teaching, there are limitations in schools when it comes to laboratory activities. This is often due to a lack of necessary equipment or simply because teachers have not been adequately trained in areas outside ‘traditional school experiments'. Furthermore, there may be health and safety reasons for not doing some of the experiments at school. With the intention of helping out under-equipped schools and inexperienced teachers, NTNU has initiated student-teacher workshops. The Resource Centre offers technical support and a wide range of workshops for school classes and their teachers where they have the opportunity to carry out those experiments they cannot, for various reasons, perform in school.

Table 2. Examples of teacher and student workshops

- Analyses of water pollution
- DNA-analyses
- Investigate family relationships within a population of House sparrows
- Electricity in modern buildings
- Build your own electronic sensor
- Build your own electronic die
- Heat exchangers
- Solar panels
- Mathematical models
- Construct your own hot air balloon
- Stereoscopic vision
- Sound sampling
- Measuring radioactivity

Teaching Resources

Several teaching resources are also being developed by the Resource Centre within the fields of mathematics, sciences and technology. This includes ideas and instruction materials for laboratory work and outdoor teaching at all school levels, booklets with background material within specific subjects, ICT-based teaching materials, books on school science and mathematics related issues and text books for a science course in secondary school. In addition, complete equipment sets with instructions have been developed for practical work in science and technology in school, such as electricity and magnetism, microprocessors, materials and constructions, fuel cells and intelligent buildings. Schools can take these sets out for loan free of charge.

Gifted Learners

Several countries pay special attention to the needs of gifted learners, and use various definitions and tools like IQ tests to define these groups. This has been a neglected area in Norway until recently. In this social-democratic country, testing of pupils is still controversial (Eurydice, 2006). Nevertheless, there is a growing awareness of the need to address this issue in Norwegian education, and the situation is improving.

As part of this process, the Resource Centre has carried out a development project in collaboration with the Municipality of Trondheim, to explore means by which the needs of gifted learners could be met, specifically in mathematics and natural science. The collaboration between the Resource Centre and Sunnland School in Trondheim was initiated in 2005, after the school reportedly had several gifted MST pupils. The school wanted to offer meaning-making strategies and teaching to bring motivation to these pupils. In order, therefore, to give academic advice in the planning, execution and follow-up of the project, the Resource Centre was involved.

More precisely, the Centre's mission was to contribute to the development of "a sustainable, holistic, interdisciplinary, motivating and alternative teaching environment for gifted MST learners" (Mathiesen, 2009, p.13). The aim was to establish good teaching practices through the development of alternative teaching materials, arenas and strategies, and moreover, to create a model for teaching gifted learners at other Norwegian schools.

In her evaluation of the project, Sissel W. Mathiesen found that not only did pupils improve their motivation in MST and other subject areas, but also that other positive outcomes were increased, such as student creativity, improved cooperation and social skills in general. Indeed, the project has aroused both national attention and has revealed that there is a significant need to provide special education and activities for gifted pupils throughout Norway (Mathiesen, 2009, p.8).

In addition to the collaboration with schools on gifted learners, a doctoral student, associated with the Resource Centre, is currently carrying out a doctoral research project on how different teaching styles and models of organization affect the success of gifted learners in science. It is likely that the knowledge that emerges within this field will allow the Resource Centre to develop resources that may be of use to schools.

Teacher Networks

Networks can be used as a component of teachers' professional development and are complementary to more traditional forms of in-service teacher training (High Level Group, 2007). Recently, a new national curriculum for primary and secondary education has been implemented in Norway. The Knowledge Promotion, in effect since 2006, is the latest reform in the 10-year compulsory school and in upper secondary education and training. Two new school subjects in science in upper secondary education were introduced, "earth science" and "technology and research". In order to provide support to schools nationwide, regional networks were established for teachers of these new subjects. These networks organise and coordinate local activities, and help to forge better links between school sectors and universities. They also act as a source of information about local initiatives and activities, and generally provide help and advice on request.

In its own region, the Resource Centre at NTNU has established a network for teachers in earth science and a network for teachers in technology and research. In addition, the Resource Centre runs a regional MST network especially for school leaders in upper secondary schools. It could be argued that having this personalized connection and facilitator-role gives a sense of ownership and personal worth to the various projects. This is supported by the literature, which suggests that successful projects begin with a locally developed community managed by a quality facilitator (see e.g., Lieberman & Grolnick, 1996).

Enhancement of Young People's interest in MST

In addition to these efforts aimed at reversing the negative trend in attitudes towards MST, children and young people also develop their interest to MST through the influence of their families, other adults, media and their own experiences. Hence, the strategies of the Resource Centre also target the general public's knowledge about, and attitudes towards, MST. Particular attention has thus been given to initiatives that go beyond the ordinary classroom and everyday school life. The aim is to experience mathematics, science and technology in a different way and in another context.

In Norway, science centres have been established throughout the country, offering school classes the chance to experience MST in a different manner. Other initiatives includes the creation of nationwide events such as the annual National Research Days and Researchers' Night, aimed at creating interest in MST amongst young people. Although the Resource Centre is not involved as an organizer of such efforts, the Centre does support the initiatives and staff members of the Centre contribute in various ways to events such as *Gründer Camp*, where the focus is encouraging entrepreneurship among school children or *FIRST Lego League* (FFL),[12] a technology tournament where young people aged 10-16 are given practical and theoretical problems to solve creatively.

The Physics Track

A successful initiative developed by the Resource Centre, two science departments and Trondheim Science Centre has been "The Physics Track" which was initiated in 2005. In 2009, the NTNU Physics Track was arranged for the fifth time and through this innovative approach, NTNU has been able to offer a total of 1277 sixth graders and 96 teachers from 36 schools the chance to participate. The goal of the Physics Track has been to promote MST in general and physics in particular. A second objective is to give elementary school pupils insights into what physics is really about, to give teachers input on how they can strengthen physics as a subject in science teaching, and lastly, to give both pupils and teachers a positive image of the university environment.

When taking the Physics Track, children pursue a route through research laboratories of various departments where they carry out experiments and explore scientific themes such as electricity, magnetism, sound waves, light and optics, water and air. Guided by a university student, groups of 6-7 children are given a three and a half hour tour where the student guides assist, explain and answer questions. The student guides have themselves received special training before guiding. Most of the Physics Track experiments are easy to carry out and may act as an inspiration for further investigations at school or at home. In addition, participating schools are invited to design and carry out their own experiments when back at school (Rossing, 2009, pp.13-14).

What are the effects, if any?

After identifying the challenges currently facing universities and schools within particular areas of MST, this report has outlined some of the efforts made by NTNU to improve the dire situation. The Resource Centre is devoting a major effort to meet the goals put

[12] http://hjernekraft.org/info-fll.aspx

forward in the National strategies, and in improving school- university collaboration in science education in general. This is important, as in-service teacher education, and the quality of MST activities seem to be a crucial issue for pupil achievement.

Is there, however, any actual proof of progress in teacher learning and student performance? To what extent does teacher development lead to better pupil learning and performance? After only ten years of existence, has the Resource Centre worked? This is not straightforward, because, as Loucks-Horsley & Matsumoto point out, better teaching and student interest may be the most difficult thing to measure in professional development (Loucks-Horsley & Matsumoto, 1999; Wilson & Berne, 1999, in Fishman et al, 2003).

Various studies have sought to assess, in more general terms, the decisive factors when pupils make future career plans. For instance, the Norwegian *Vilje-con-valg* project and its international follow-up project, IRIS (Naturfagsenteret, 2009), as well as two Masters theses by NTNU students, suggest that role models and parental influence play a far more prominent role than, for example, information campaigns.

Oscarsson et al (2009) have shown that Swedish secondary school teachers in science believe that out-of-school experiences are important for pupils' interest in science and technology, whereas studies at NTNU indicate that this is the case only for some pupils. Good teachers in mathematics and science seem to inspire some pupils, but other pupils do not seem to be influenced, either positively or negatively, by their mathematics and science teachers.

In his analysis of the university as a promoter of MST in schools, Van Marion comes to similar conclusions. Better teaching and pupil performance are hard to identify, nor is it possible to measure whether the Centre's activities have led to more positive attitudes towards MST. Even if teachers are better motivated after undertaking professional development courses, it is still difficult to evaluate whether they actually apply this knowledge to their classroom practice.

In this sense, a possible area of improvement may be to evaluate more extensively the courses and their impact, including better follow-up research with the teachers to gather feedback on their experience of the activities.

Nevertheless, after reviewing the practical underpinnings of in-service teacher professional development, this report finds that the Resource Centre directly targets the challenges outlined in the national strategies, namely declining student interest and performance, and enhancing the professional development of teachers. There are also strong indications that teachers benefit from the services that are offered, and reasons to believe that the sum total of efforts put into strengthening MST teaching in schools may affect performance of Norwegian learners in international studies such as TIMMS and PISA. In particular, it seems appropriate to assume that the efforts being made to strengthen the qualifications of MST teachers in schools will be an investment, which, in the long term, will give positive results.

The report has also shown that, after nearly a decade of work the Resource Centre has contributed to a wider and stronger involvement of NTNU's scientists in mathematics, science and technology teaching in school.

This development has been made possible by communicating the needs of school science teachers to the university experts, and at the same time contributing to making the expertise of university staff more available to teachers. This helps university staff to "hit the target" in a better way and it helps maths and science teachers to articulate their needs for updating and teaching resources in a better way. In the long term, this stimulates stronger engagement and involvement from university staff in primary and secondary education.

In other words, the University and the Resource Centre have a number of roles both at the systemic level and at the individual level: teaching the teachers; teaching young people; guiding and organizing; supporting teachers by facilitating collaboration and interaction between school and university in science education. In fact, numerous maths and science teachers have taken part in in-service training at NTNU or benefited from other services provided by the Resource Centre. In sum, these programmes purport to be relevant and practical, timely and topical, and are generally appreciated by teachers who are accustomed to working in isolation with little support. Pupils also seem to be satisfied participants.

Summary

This report has described how NTNU approaches the challenges related to school-university collaboration in science, mathematics and technology education. The case of the Resource Centre has provided insight into a diverse range of teacher professional development activities. It has been shown that the Resource Centre offers a broad understanding of in-service teacher professional development.

It is difficult to identify one single factor for successful university-school collaboration. Rather, multiple factors seem to be decisive, both for improving TPD and influencing the choices that pupils make in terms of further studies and professional career. Fishman et al (2003) provide a nuanced analysis, stating that no one solution or approach is correct, but that all professional development is context bound. Similarly, following Craig et al. (1998) and Tatto (1997), it is important to think of teacher professional development as a continuous process, and not simply a time-bound activity or series of events. The strength of such a broad view is that it encompasses a variety of approaches, thereby avoiding an “either/or” view of TPD and school – university collaboration.

Recommendations for further university – school collaboration in science

The two day seminar held April 8-9th in Trondheim, Norway, gave a presentation of NTNU’s activities to one of its partner institutions, Mälardalen University of Sweden. In addition, representatives from Physics and PLU at NTNU participated, as well as staff members from the Research Centre. The seminar aimed to provide a guide for school-university cooperation by bringing together expertise to discuss the roles of the different actors as well as cross-country experiences.

The discussion evolved around the role of universities in MST education in schools more generally, and the experiences from all participants were discussed and compared. The seminar reinforced the need to focus on some particular guidelines for interaction and collaboration in the field of in-service training and other activities aiming at improving the quality of MST teaching in schools. Indeed, the debate led to some fruitful conclusions from where to form valuable recommendations.

The seminar discussion can be summarized by the following main recommendations for interaction and collaboration between schools and universities;

1: Listening to the school teachers

The first point refers to the importance of universities listening to the school teachers. As the case study shows, it seems that the right approach to TPD to a great extent depends on local needs and conditions. Indeed, the configuration of cooperation and dialogue between schools and scientists seem to vary both across regions in Norway as well as across European countries. As such it is essential to *show greater* understanding towards the specific needs of participants regarding in-service training, building on the request of the stakeholders in these courses, namely the school teachers and the higher representation of schools, the Municipality, as well as the heads of schools. At the same time, universities should also exercise some influence in the process, helping schools to develop their competencies in a more systematic way.

For instance, finding flexible solutions in the case of Sunnland School (as earlier mentioned) meant developing a program designed to give special attention to the needs of gifted learners (Mathiesen, 2009). This became more of a tailor-made project where both the Resource Centre, the school as well as the Municipality invested in development. Other schools may however have other needs, where for instance groups of math or science teachers are offered school-based programs largely based on the specific needs expressed by the participating teachers.

In other words, this is not a static process, the needs of schools may change constantly, and as such, it is of crucial importance that schools themselves communicate where the emphasis should be and where efforts should be placed. This will help universities and collaborating partners to more easily identify what approaches are most appropriate in which situations, also making universities able to influence decision makers on what areas to prioritize.

A good dialogue between the teachers on the one hand, and the universities on the other hand, should also enable universities to respond more quickly to the schools' changing needs, something which brings us to the second recommendation.

2: Adequate response to changing needs

If there is a greater clarity of the needs of the various schools, then the effectiveness of the initiatives improving these needs may arguably be intensified. Only when the schools have reported their weaknesses and adjustments are made accordingly, is it possible to make a judgement on the outcomes. In some cases, the request is more urgent and a short term solution is needed. Yet, schools have, as noted, different conditions and starting points for improvement. For instance, the above mentioned gifted learners initiative was specifically designed for one school, whereas a more holistic approach has been to initiate the Physics, Biology and Chemistry Tracks. It seems that, in at some cases, the remedy is offering individually tailored solutions, whereas in more general issue matters, such as improving MST among students as a whole, a more general approach may be more useful.

There are many actors in this process, including teachers, trainers and the learners themselves. In this context, the Resource Centre has a crucial part, being able to rapidly develop in-service course packages due to its extensive expertise, web of partners, networks and the competence to coordinate these with the schools needs in practice.

3: School relevant content

The seminar participants stressed the importance of having a broad understanding of pedagogical content knowledge, hereunder a particular emphasis on school oriented content in the in-service courses. In other words, when arranging a course on, for instance, radiation, there is a need for balance to ensure that all necessary aspects are covered. The scientific knowledge should to be included obviously, but also at the same time, it was argued, an awareness of the methods, as well as the content of curriculum is vital, ensuring that the content is taught in a school perspective, having a learner-centred approach to curriculum.

As the background to this discussion, it was also stressed that language is an important pedagogical tool, and that teachers should be more aware of how they use communicative methods when engaging with learners, who often have various cultural backgrounds and different starting points as regards communication in a school setting. In addition, the need for more attention and openness to the various dimensions of interdisciplinarity in teaching and learning situations was highlighted.

4: Direct contact with university researchers

To have a close cooperation between schools and researchers (experts) should be a primary goal. The interaction between students, teachers and university staff is important because of several factors; first and foremost it gives a unique hands-on experience to teachers and students, who are often under-equipped and without adequate resources. As experts within MST, university researchers can update teachers in schools with new knowledge within their fields of expertise, create renewed awareness of the relevance of research and development within MST and inspire teachers to teach MST in new ways. Secondly, school-university collaboration in science education gives universities invaluable insight in the school world, and vice versa. Furthermore, having good role-models within the field of MST may further recruitment, which should be welcomed, knowing that most western countries are experiencing a noticeable decline in recruitment of students of various MST programs (Norwegian Ministry of Education and Research 2010-2014).

To sum up, this seminar emphasized that the development of school-university collaboration requires a coherent approach involving cooperation and dialogue between schools and university. This entails designing a system where universities are able to quickly respond to the schools' changing needs, and where courses and scientific knowledge are taught keeping the school perspective. It also means having an awareness that 'curriculum' encompasses all aspects of learning, including various curriculum areas and subjects, interdisciplinary learning and opportunities for personal achievement within and outwith the school.

Building on the recommendations above, the aim is that universities and schools should be able to approach this matter in a more systematic way and as such improve the quality of MST teaching in schools.

References

Adajian, L. B. (1996). Professional communities: Teachers supporting teachers. The Mathematics Teacher, 89(4), 321–326.

Borko, H (2004) Professional Development and Teacher Learning: Mapping the Terrain, *Educational Researcher*, 33 (3).

Craig, H., Kraft, R.J., & du Plessis, J. (1998). *Teacher Development: Making an Impact*. Washington, D.C.: U.S. Agency for International Development and World Bank.

Eurydice. (2006) *Science Teaching in Schools in Europe*, Brussels: European Commission, Eurydice

Fishman, B., Marx, R.,Best, S.,Tal, R. (2003) Linking Teacher and student learning to improve professional development in systemic reform, *Teaching and Teacher Education*, 19, 643-658.

Grossman, P., Wineburg, S & Woolworth, S. (2001). Toward a Theory of Teacher Community. *Teachers College Record*, 103, pp. 942-1012, available at http://www.tcrecord.org/Content.asp?ContentID=10833

High Level Group on Science Education. (2007) *Science Education Now: A Renewed Pedagogy for the Future of Europe*, Brussels: European Commission, Directorate- General for Research.

Lieberman, Ann & Grolnick, Maureen (1996) Networks and Reform in American Education, Teachers College Record, 98/1, pp.7-46.

Little, J. W. (2001) Professional development in pursuit of school reform. In A. Liebermann, & L. Miller (Eds). *Teachers caught in the action: Professional development that matters*, New York: Teachers College Press, 23–44.

Marion, P. van (2009) The University as a Promoter of Mathematics, Science and Technology in School. *Proceedings of the International Conference Global Cooperation in Engineering Education* Kaunas. Kaunas University of Technology

Mathiesen, S.W. (2009) *Tilpasset oppløring for særlig realfagsterke elever, Sunnlandsprosjektet, 2005-2008* Trondheim, NTNU Rapport.

Naturfagsenteret (2009) *Vilje-con-valg*. Retrieved September14, 2009, from www.naturfagsenteret.no/vilje-con-valg

Norwegian Ministry of Education and Research (2006) *A Joint Promotion of Mathematics, Science and Technology (MST)*. Oslo: Norwegian Ministry of Education and Research. Retrieved September 14, 2009, from www.naturfagsenteret.no/Strategiplan2006_eng.pdf

Norwegian Ministry of Education and Research. *Strategy 2006-2009. A Joint Promotion of Mathematics, Science and Technology*. Oslo; Norwegian Ministry of Education and Research.

Norwegian Ministry of Education and Research. *Strategy 2010-2014. MST for the Future.* Oslo: Norwegian Ministry of Education and Research.

OECD (Organization for Economic Cooperation & Development) (2009) *Creating Effective Teaching and Learning Environments: First results from TALIS*, Paris, OECD.

http://www.oecd.org/dataoecd/17/51/43023606.pdf

OECD. (2006) *Evolution of Student Interest in Science and Technology Studies – Policy Report* Paris: OECD, Global Science Forum.

Osborne, J. & Dillon, J. (2008) *Science Education in Europe: Critical Reflections, A Report to the Nuffield Foundation*, Kings College, London

Oscarsson, M. Jidesjö, A. Karlsson, K.-G. and Strömdahl, H. (2009). Science in society or science in school: Swedish secondary school teachers' beliefs about science and science lessons in comparison with what pupils want to learn. Nordina 5(1): 18-34.

Rossing, N. (2009) Rapport fra Fysikkløypa 2005-2009 Norges Teknisk - Naturvitenskapelige Universitet

Ruopp, R & Haavind, S (1993) From current practice to projects. In R. Ruopp, S. Gall, B. Drayton, & M. Pfister (Eds.), *LabNet: Toward a community of practice*, Hillsdale, NJ, Lawrence Erlbaum Associates

Schlager, M Fusco, J. & Schank, P (2002). Evolution of an on-line education community of practice. In K. A. Renninger, & W. Shumar (Eds.), *Building virtual communities: Learning and change in cyberspace*, New York, Cambridge University Press.

Tatto, M.T. (1997) *Limits and Constraints to Effective Teacher Education*, in Cummings, W. and McGinn, N. (Eds.) *International Handbook of Education and Development: Preparing Schools, Pupils and Nations for the Twenty-First Century*, New York, Pergamon Press. 213-230.

Other sources:

S-Team Preliminary Report, Work Package 2/3, January 2010

Eurydice : www. Eurydice.org / http://eacea.ec.europa.eu/education/eurydice

www.skolelab.ntnu.no

TIMSS: www.timss.no / http://www.iea.nl/timssadvanced20080.html

TALIS:http://www.oecd.org/document/54/0,3343,en_2649_39263231_42980662_1_1_1_1,00.html

PISA : http://www.pisa.no

www.oecd.org

http://hdr.undp.org/en/statistics/

http://ourtimes.wordpress.com/2008/04/10/oecd-education-rankings/).

FFL: http://hjernekraft.org/info-fll.aspx

http://www.ntnu.no/forskningsdagene/researchnight

Appendix 1: The Physics Track

1.1: Short Summary

2005 was entitled “The World’s International Year for Physics”, to commemorate Albert Einstein’s three articles that were published in 1905. These articles came to have great significance for physics in the 20th Century. Against the backdrop of this, the Physics Track began in 2005, as a collaborative project between the Physics Institute and the NTNU Resource Centre.

With the aim of advancing physics education, all elementary schools in the district were invited to participate. As a result of the overwhelming response (1100 registered pupils during the first year), the Physics Track is now arranged annually on a permanent basis.

This is the 6th year that NTNU Physics Track has been arranged, and through this innovative approach, NTNU has been able to offer a total of 5700 pupils from 6th grade the chance to participate. NTNU has financed the project since 2008, however, since 2009 it has been co-financed through Centre for Science and Samarbeidsforum.

1.2: Aims of the Physics Track

Interest in sciences or technology usually develops at young age. The quality of science teaching at lower grades in school, it is often argued, may be of crucial importance in determining these pupils’ career choices later in life. A glance at the academic literature, however, suggests that there seems to be a common concern about the general lack of expertise of mathematics, science and technology (MST) among teachers.

The goal of the track has thus been to increase interest for MST, in particular as regards physic subjects. A second objective is to give pupils in elementary school insights into what physics is really about, to give teachers input on how they can strengthen physics as a subject in science teaching, and lastly, give both pupils and teachers a positive image of the university environment.

1.3: What is the Physics Track about?

NTNU has various science departments as well as research laboratories. The structure of the Physics Track is a route through these research labs, where pupils are able to carry out experiments and explore scientific themes such as electricity, magnetism, sound waves, light and optics, water and air. Most of the Physics Track experiments are easy to carry out and are intended to serve as inspiration for further investigations at school or at home.

During the tour, each group of 6-7 children is guided by a university student in science or engineering. The pupils who work as guides for the NTNU Physics Track have all received special training. They guide their group of children through the track, from laboratory to laboratory, moreover, assist and explain where necessary and seek to answer the children's questions. The whole tour takes about 3.5 hours, time for lunch included. After completing all experiments, the children receive a diploma confirming their participation in the Physics Track.

The success of the track has even led to further initiatives. In 2007, the Institute for Biology developed the Biology Track, followed by the launch of a Chemistry Track in 2009. In the Biology Track, pupils in the 9th grade complete a route of 10-12 posts where they, in groups of 6, solve problems and tasks in topic areas such as plants, birds, animals and insects. Pupils may also explore DNA in electro-microscopes and are introduced to various other issues linked to biology. The Chemistry Track for 7th graders consists of 8 posts where pupils are able to perform easy chemistry exercises and experiments. Since 2005, NTNU has arranged two Biology Tracks with a total of 1300 pupils from 9th grade as well as a Chemistry Track with 650 pupils from 7th grade (Rossing, 2009,13).

1.4: Evaluation of the Physics Track by pupils and teachers

According to a survey assessing the significance of the track for pupils and teachers during the period 2005-2009, the overall assessment is relatively positive. In fact, 45 per cent of the teachers state that they have benefited from the services provided by the Resource Centre, in the sense that the track has increased pupils' interest and motivation regarding MST. Only 5 per cent claim that the track has had little or no impact on pupils (Rossing, 2009,p.27).

In short, this suggest that both teachers and pupils profit from the Physics Track, indeed it is relevant and generally appreciated by teachers who are accustomed to working in isolation with little technical support.

On the other hand however, according to the same survey, only 16 per cent of the teachers claim they are able to follow-up and effectively use their newly acquired knowledge (Rossing, 2009, p.27). There is arguably then, a necessity for more structured follow-up of programmes and courses.

Reference

Rossing, N. (2009), Rapport fra Fysikkløypa 2005-2009 Norges Teknisk - Naturvitenskapelige Universitet

S-TEAM Product 5.7 (Preliminary version): viten.no –digital teaching programmes in science education

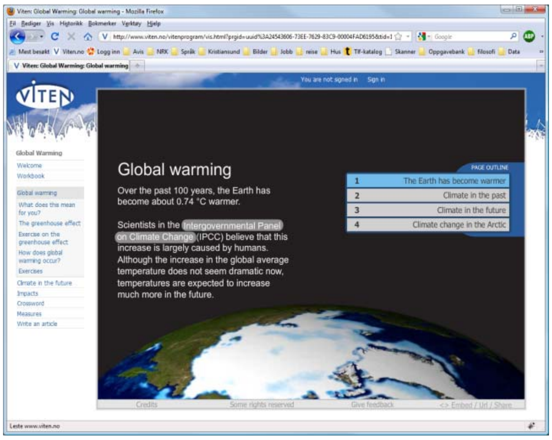
The viten team, University of Oslo

viten.no is a web-based platform providing digital teaching programs in science for grades 8-12 developed by the Norwegian research and development project Viten (Jorde, Strømme, Sørborg, Erlien, & Mork, 2003). Viten.no is well established within Norwegian schools and has at several occasions been nominated as a good example of digital learning resources in the Norwegian context. The Viten teaching programs are free to users.

Viten was established in 1999 by Doris Jorde and Alex Strømme as a research and development project between the University of Oslo (UiO) and The Norwegian University of Science and Technology (NTNU). The Viten project is now directed by the Norwegian Centre for Science Education.

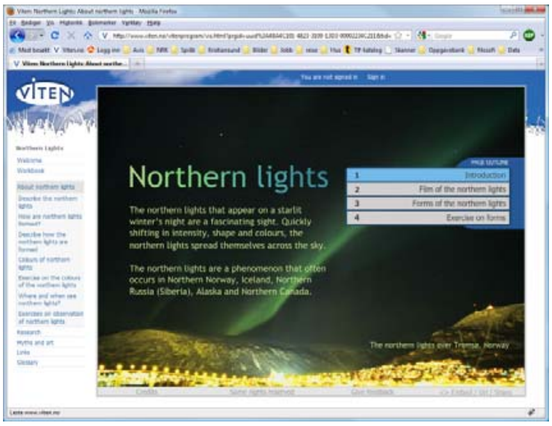
Students can work collaboratively on various science topics and each topic ranges in duration from 2-8 science lessons. Three types of programs are available, engaging students in: a) designing solution to problems, e.g. design a greenhouse for growing plants in a spaceship on its way to Mars, b) debating controversial issues, e.g. whether or not there should be wolves in the Norwegian wilderness, c) investigating scientific phenomena, e.g. radioactivity, gene-technology.

Since launching viten.no with three teaching programmes in winter of 2002, 16 teaching programs are available in Norwegian by April 2010. So far three programmes are translated into English:



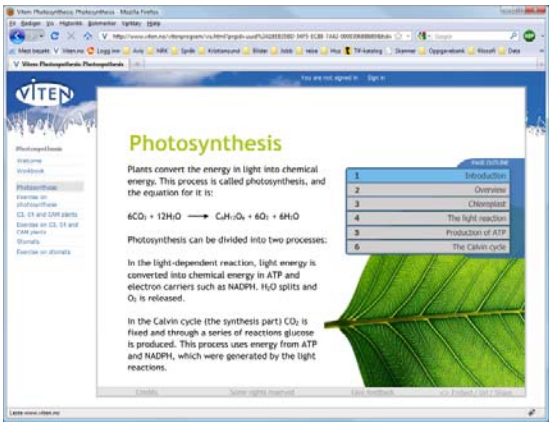
Global Warming

Run a climate model to see how the climate probably will change in 100 years! See how far a polar bear roams over the course of a year! Do experiments with ice cubes modelling the Arctic and Antarctica and see how the sea level changes if the Earth temperature increases!



Northern Lights

Animations and interactive exercises introduce students to how northern lights are formed, and how Norway and Norwegian researchers have been and are central to northern lights research.



Photosynthesis

Animations and interactive exercises about photosynthesis.

Many of the learning objects - or *Viten objects* as we call them - can be used separately or integrated in other web pages. Objects with this compatibility, have a button down on the right: <> *Embed / Url*. The URL popping up is the address of the actual Viten object. This link can for example be used to link the object into a LMS. The HTML code in the embed field can be used to embed the object into a web page that allows for this, such as a blog.

Figure 1: Screen shots showing the Embed/Url feature.

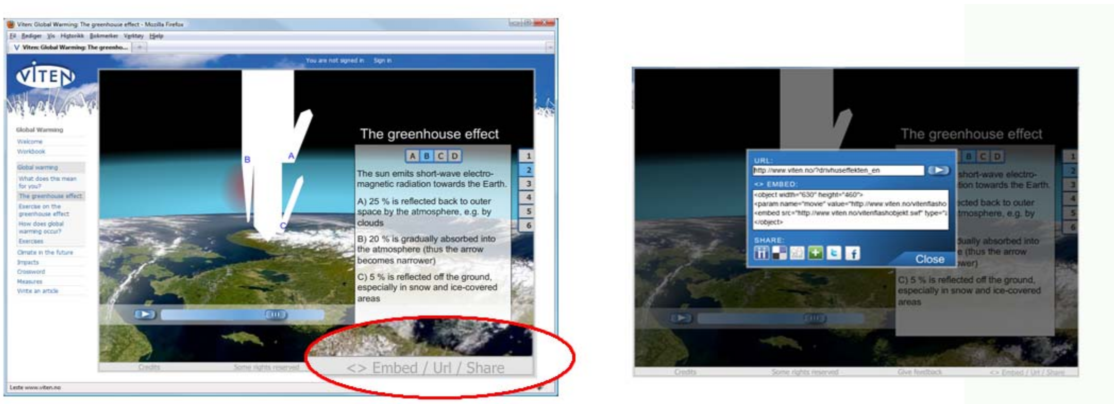
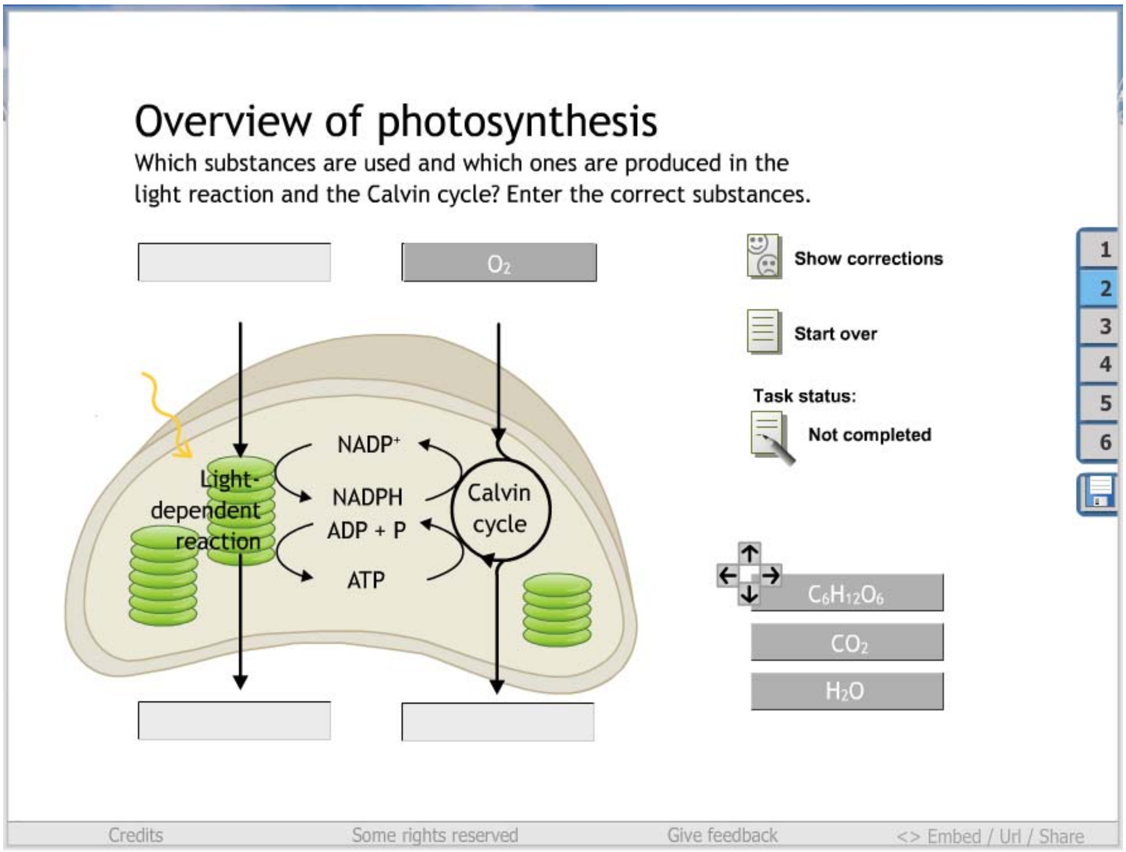


Figure 2: Examples of external web pages embedding *Viten objects*.

Figure 3: The *Viten objects* support keyboard accessibility (use of e.g. the keys tab, arrows, enter etc), and also the use of drag-and-drop.



Viten builds on ideas of exploring the effective uses of technology in supporting the way scientific information may be presented and used as students learn science. The research and design activities of Viten are based on a continuous improvement model (Table 1) combining development of teaching programs with classroom evaluation (Jorde et al., 2003). All Viten teaching programs are developed in teams consisting of teachers, science educators, ICT technicians and experts from the academic discipline. Once themes have been constructed using the Viten software toolbox, implementation studies are conducted in science classrooms where members of the Viten team participate as classroom researchers.

In order to understand the challenges faced by teachers and their students while implementing Viten programs, one must take into account the realities of everyday life in science classrooms and school systems. Pre- and post testing is included as means of monitoring conceptual growth. Groups of students working in front of the screen or participating in debates are videotaped to better understand the role of social discourse when learning concepts. Responses collected in the Viten programs are used to analyse conceptual growth while students work with the programs. Students are interviewed before and after working with programs to provide information on their views of the use of ICT and their knowledge about actual science topics in contextual settings.

Table 1: Overview of components in the Viten design model and its specifications.

Viten design model	***Specifications***
1. Choice of topic	*Types of Viten programs:* *Designing solutions to problems* *Debating controversial issues* *Investigating scientific phenomena*
2. Establishment of expert group	*Group members:* *Programmer* *Science educator* *Subject expert* *Teacher/student*
3. Development of Viten program	*Design principles:* *Making science accessible* *Making thinking visible* *Help students learn from others* *Promote autonomy and lifelong learning*
4. Classroom trials/ Evaluation of results	*Data collection:* *Pretest/posttest/delayed posttest* *Classroom observations/video* *Student/teacher interviews* *Student logs*
5. Repeated revisions of program	*Main revision after classroom trials. Revisions are also made as a result of feedback from students, teachers and others, and when new information in the field becomes available.*

The Viten design model stresses the fact that students not only need scientific information when learning science, they also need to be able to apply that knowledge in actual situations. The model also emphasises the need to integrate scientific topics into other domains such as economics, history, geography and sociology, which may influence how society deals with scientific information in a broader context.

Students are encouraged to work in pairs in front of the computer while working on Viten programs. Some of the clearest benefits of classroom computer use arise from the fact that they lend themselves so well to collaborative modes of use (Crook, 1994). The Viten philosophy is that students must formulate and explain their own ideas to each other, and through discussions work out common answers to tasks. Students like working in pairs, something that may also increase motivation. This work form can nourish confidence when students work on difficult topics, or if they are not comfortable with using computers.

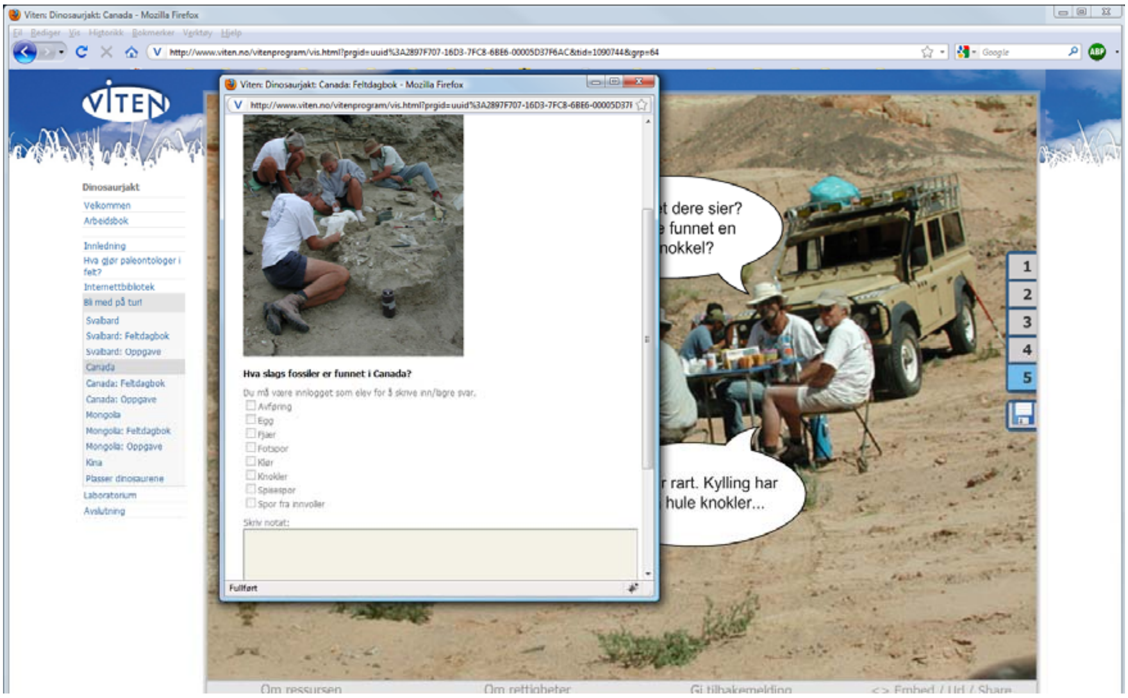
Each student pair has their own workbook integrated in viten.no, where the teacher can comment on their work at any time. All Viten programs are composed as learning environments providing a wide variety of activities like animations, note-taking tool, quizzes, video clips, interactive tasks, simulations, evidence pages, links to other web-pages, crosswords etc as illustrated in Figure 1.

Figure 4: Screen shots from various activities in the Viten programs.

Most Viten programs end with a final activity where students are challenged to apply information from the program in contexts such as; an offline debate, write a newspaper article, an oral presentation or even the building of a greenhouse to grow plants in space.

Figure 5 visualises the Viten student interface by a screen shot taken from the Viten program *Dinosaurs and Fossils*, where the student mission is to go on a virtual tour collecting evidence that support or reject the theory of kinship between dinosaurs and modern birds. Students navigate through the program by following the steps in the menu on the left. Each heading in the menu is a unit consisting of several steps. The pop-up window is the student researcher's field notebook, where they register evidence from each location they visit on their virtual tour.

Figure 5: *Viten student interface showing pop-up notes window.*



We welcome comments and feedback as users of Viten!

References

Crook, C. (1994) *Computers and Collaborative Experience of Learning*, London, Routledge.

Jorde, D., Strømme, A., Sørborg, Ø., Erlien, W., & Mork, S. M. (2003) *Virtual Environments in Science*. Viten.no (No. 17). Oslo, ITU.

Mork, S. M. (2006). *ICT in Science Education. Exploring the Digital Learning Materials at viten.no.* Unpublished Doctoral thesis, University of Oslo, Oslo.

Mork, S. M. (in prep.). *Design and Implementation of the Web-Based Viten Program Radioactivity*. in preparation.

Other publications in English

Mork, S. M. (2009): An interactive learning environment designed to increase the possibilities for learning and communicating about radioactivity. Interactive Learning Environments. DOI: 10.1080/10494820802651060

Jorde, D., & Mork, S. M. (2007). The contribution of information technology for inclusion of socio-scientific issues in science: The case of wolves in Norway. In D. Corrigan, Dillon, J. & Gunstone, R. (Eds.): The Re-emergence of Values in the Science Curriculum. Sense Publications.

Mork, S. M. (2006). viten.no - digital teaching programs in science education. NorDiNa 3, 84-88.

Mork, Sonja M. (2005) Argumentation in science lessons: Focusing on the teacher's role. *NorDiNa* 1(1):17-30

Mork, S. M. & Jorde, D. (2004) We know they love computers, but do they learn science? A study about the use of information technology and controversy in science instruction. *Themes in Education*, 5(1), 69-100.

Mork, S. M. & Jorde, D. (2003) *Using information technology and controversy to* promote argumentation in science lessons. Paper presented at the ESERA conference in the Netherlands.

S-TEAM Product 5.1 (preliminary version): Initial Teacher Education: Guide for Teacher Educators in Inquiry-based Science Teaching

Jim McNally, University of Strathclyde

Introduction

This paper is a first draft of a Guide for Science Teacher Educators in Initial Teacher Education (ITE). It lays down a set of arguments in support of Inquiry-based Science Teaching (IBST) as sections to be further developed. It also includes a number of references, apposite quotes and exploratory small scale research. The intention is that the paper will be used as a basis for the development of a website that will have links to:

the sections as briefer chunks of text less than a page

quotes from a range of sources

video / audio clips from a range of sources

published papers from research, policy and practice (hyperlinks)

other useful websites

The Science Curriculum in Scotland tends to refer to investigations in Science, so inquiry and investigation are used interchangeably in this paper.

Section 1: Why is inquiry-led science education important?

We can look to a number of sources to support the case for more inquiry or investigation in science teaching. There is a substantial body of evidence and argument in the education literature (see, e.g. Roth,2002; Hodson 1999) . There are also reservations about whether inquiry is justified in principle (Kirshner, Sweller & Clark 2006), but they do not tend to engage with the reality of science classrooms or the successes of teachers and pupils, even in terms of inquiry based learning. Often writers needlessly polarise positions on inquiry and fail to recognise the complexity of teaching and the fact that teachers employ a range of approaches that cover traditional transmission, resource-based learning, field work and even, ideally, inquiry in their science classrooms and other sites of learning. However, this body of literature has had little effect on advancing inquiry as a method of teaching Science. The writing of academics tends not to reach as far as practice in the schools, leaving a gap that the current project seeks to bridge.

(Our Website Guide will have links to any publications that are cited)

Science itself is perhaps too often presented as inexorably sequential and rational in its generation of knowledge. There is so much knowledge that the required knowledge content of the science curriculum tends to dominate syllabus statements, textbooks and other resources that teachers tend to use. Yet there is much evidence that the development of knowledge by scientists owes a great deal to unplanned events and chance connections.

> … trying to interpret the future directions of science, it helps to remember that the great discoveries are rarely the outcomes of deliberate searches for universal answers, but more often the unanticipated dividends of careful research focused on modest, specific questions (APS, 2010).
>
> In 1900 Planck made the breakthrough (towards a theory of quantum mechanics), not through a cool, calm and logical scientific insight, but as an act of desperation mixing luck and insight with a fortunate misunderstanding of one of the mathematical tools he was using (Gribbin, 1998, p.37).
>
> The most exciting phrase to hear in science, the one that heralds the most discoveries, is not 'eureka!', but 'that's funny…'" (Isaac Asimov, science fiction writer and research chemist)

Admittedly, scientists have a solid grasp of their discipline and bring this advanced knowledge to their inquiry but, at a more elementary level, learners in school do have knowledge in development through a planned science curriculum. Even at this level, questions arise which may be pursued from a base of knowledge and practical technique, as and when it is covered – or perhaps some time after coverage - in a particular science curriculum.

It is this openness to questions and the opportunity to pursue some of them at least that brings inquiry into science education and thus into the learning experiences of pupils – and their teachers. These activities are typically not grand designs – they need not and probably should not be – but they are the early play of an education in doing science, of doing what scientists do. The questions are likely to be modest of course but are also likely to emerge from prescribed work and be of specific interest at that time. If the questions are caught in the moment, are relevant to their work, and pupils are judged ready to follow through on the question, then there is a real chance of very 'successful learning' (to quote one of the four capacities of the new curriculum in Scotland). Whether learners or teachers employ the conventional discourse and categorisation of scientific procedure – observation, hypothesis formation, variables, method and so on…is not important at this stage. These concepts and terminology will emerge in due course in the hands of the educated teacher of science. What is important is that the received terminology of scientific method does not obstruct or impede the initial impetus of inquiry and fracture the integrity of the endeavour as a holistic experience in context. The teacher can introduce points of scientific method as and when pupils are judged ready to use and understand such language. This leads us to the question of the 'educated' teacher of science, a central purpose of the S-TEAM Project and of this guide for the start of that education.

Section 2: Getting started

In a modest pilot study of student teachers, we asked them about their early experiences of opportunities for investigative work in the science classroom. We required only brief responses but the following examples nevertheless demonstrate what is possible, even in the early stages of their development as teachers:

> The next lesson in the series looked at the use of chromatography in the separation of different inks or dyes. A pupil asked if the ink in the felt tip pens the class were using was one ink or a mixture of different inks. This presented an opportunity to carry an experiment to determine which inks made up the colours in the class's favourite felt tip pens. The pupils were especially surprised at the presence of bright blue or yellow ink in a black felt tip pen. This final experiment really cemented the notion that a mixture is something which can be separated in pure substances. I found the use of relevant real life examples was invaluable for explaining relatively abstract concepts and cemented the pupils understanding.

> An investigative task I carried out with a first year class was an investigation into the pH of soft drinks. This was a great task which was very simple to set up and the kids really enjoyed. It was relevant to their lives and they were very keen to find out the pH of their drink of choice! This obviously tied in well to the Acids and Metals topic and got the children to use pH paper, measuring cylinders and practise recording their results…This investigation allowed the children themselves to

> discover that the fizzy drinks had a high acidity and they then started asking questions such as "what does that do to your teeth?" etc which led nicely on to a lesson with photos of corroded and damaged teeth. The kids all wanted to test their own juice and left the lesson talking about how they "won't be drinking that again"…Questions about what could be done about it led on to the pH of toothpaste which we then tested in the next lesson … The lessons were fun and easy to manage because the children were so involved.

The examples from the students suggest that getting started may be much easier than we have so far thought. We ourselves have identified components of confidence for teaching investigative science and suggested caution in its introduction (McNally, 2006), but the opportunities appear to be closer than we realised and the possibility of practice much earlier. What is clear is that the standard activities within the science syllabus itself often have within them the potential for feasible inquiry and achievable success. They are there in front of you and need not take much if any extra time; indeed some prescribed activities are investigative in form or can be made so through a simple rephrasing of the aim or purpose.

There were of course reports from the students in which they were unable to pursue inquiry or it was deemed unfeasible. Of the 28 students we sampled, a few reported that the required resources were not readily available or that inquiry was discouraged by colleagues because of pressure of time or examinations:

> After discussing friction, the next question was, "What would happen if we put butter all over the ramp?" As before, the class predicted that the sledge would have more E_K as the butter on the ramp's surface would reduce friction and allow the sledge to travel faster. Unfortunately, we could not carry out either of these extensions to the investigation as we ran out of time. We also had no wheels. And no butter.

> Unfortunately throughout my school experience I did not witness an "investigative learning "activity. The pressure of meeting deadlines and ensuring the adequate preparation of students for upcoming exams constricted teachers from deviating from focusing upon these priorities.

> I did notice in the learning outcomes of the S1 and S2 topics that there were investigations outlined and suggested for pupils to carry out. However, I did not see any being utilised by the teaching staff. I asked members of staff if they had or ever used the investigations and received similar responses from each of them; that due to a lack of time, they very rarely if at all, used the investigations. The teachers felt that they were generally pressed for time to complete each topic and test the students.

It is often claimed that the enthusiasm and idealism of new teachers is curtailed by a prevailing culture of conservatism in schools but, though we have given the only three examples of this above (from 28), it is not clear if the remarks were particular to that activity or meant as a general point. We would not, therefore, want to invoke that rather untested assertion that teachers in school discourage students on placement, in developing our case for promoting inquiry in science classrooms. Many may well be doing investigative work without either realising it or reporting it - or they may simply think it is not worth making a fuss about it.

Another point to make here is that beginning teachers probably benefit from engagement with the experiences of more experienced colleagues, directly so during placement, but also (indirectly) through second hand contact with their accounts. Such accounts would be of actual experiences and take a variety of forms – text, audio or video. They would probably be fairly brief (perhaps five minutes maximum) and act as a basis for discussion by students. One of our S-TEAM colleagues already has some evidence to suggest that student teachers engage well with brief video clips of teachers in action in the classroom. We would suggest from our own experience of working with beginning teachers and researching their learning experience that this approach should be pursued as an important element in the education of the nascent teacher of science. It may also be that a conceptual model of experienced teachers' thinking can also be introduced to students at this stage, one that clearly accommodates the range of actual examples given and discussed. Although some tentative progress has been made on such theorising, there is still some way to go on developing an empirical basis of support for any strong theoretical claims.

Section 3: Types of engagement

What do we know of how student teachers engage with Investigative Science? From our pilot study we have first of all learned that some of them already do or can engage. Our analysis of their brief reports suggests that their engagement may be categorised, although we have still to further discuss and develop this as a possible typology   Initial thoughts are that how the inquiry is originated is important. We have found origins of investigative activity in:

The prescribed curriculum topic

Close and parallel relation to/ arising from the prescribed curriculum topic

Separated from a curriculum topic

The actual initiation of the inquiry needs some human agency of course. In the case of the prescribed curriculum topic, the teacher is the main agent, drawing on the curriculum as written. The degree to which children engage with a prescribed topic is largely determined by teacher quality; there may well be cases where little engagement takes place, despite the efforts of the curriculum writers. Then there are situations where opportunities for inquiry are recognised in the course of following the prescribed activities. This may come from the teacher or from a question by the pupil – examples of both – probably both are important – we could argue that if a teacher sees opportunities then she is more likely to be disposed to nurturing the formation of questions by children and indeed the pursuit of them, where feasible. Investigation can therefore be teacher-led or pupil-led with teacher support – and are there different levels of teacher support? We would question, however, whether the larger scale investigations required through formal assessment schemes do in fact foster a spirit of investigation.

There is therefore no obvious basis for categorising types of investigative activity at different levels. This would imply grades of difficulty or of sophistication or of pupil impact and so on. These are not yet clear and perhaps do not matter. Nor have we yet examined differences according to year or stage of learners, though we do have examples from S1 to S6 (but no Primary Teachers as yet).

Section 4: Connections to a bigger picture

Learning science through inquiry is vitally important but there are other ways of learning. There are times and topics when the teacher may judge that other methods are more appropriate. Inquiry-based learning as a practical ‘hands-on’ experience is also an essential part of developing an understanding of the nature of science, through participation in the process as well as in making meaning of ‘content’. However, not all questions can be followed through in practical way in school so there should be space for pupil discussion. Indeed discussion should have a place in its own right. Perhaps because of the amount of knowledge that has accumulated in science and the need to ensure that pupils obtain an adequate grounding in that knowledge, covering that knowledge base as curriculum content tends to dominate both curriculum and pedagogy in science to a greater extent than other subjects and areas of the curriculum. It is argued that teachers of science have difficulty in managing discussion in the classroom Yet there are so many potential opportunities for discussion, particularly from contemporary life where there are major advances in science and social and ethical issues that are often raised by these advances. The science underpinning these advances should be brought into the classroom by the teacher as accessible knowledge and discussion by pupils encouraged. There is much to be learned by teachers of science from teachers of other subjects on how to manage discussion. In Initial Teacher Education, therefore, student teachers of science need the opportunity to practise and observe classroom discussion, both on placement and within their university programme under the tutelage of university tutors who themselves may need to develop their own understanding. Current developments in co-operative learning, for example may be a useful reference.

We might also expand this section to include reference to the development of scientific ideas as a historical perspective, the biographies of scientists and indeed the philosophy of science. If an education in science is to be more authentic, then we could argue that students ought to practise and promote a more authentic science through inquiry, discussion and engagement with more topical and human dimensions. This would require that they be introduced into ITE, as an introduction to the nature of science - practically through experiences and principles such as those covered above in this paper, but also theoretically and philosophically; and that this be continued into teachers' professional development post-qualification.

Section 5: What (evidence) will persuade teachers?

Perhaps the most persuasive evidence comes from teachers themselves – from their stories, observations and interactions. This paper supports and illustrates that argument and recommends that development of a pedagogy of inquiry or investigation is more likely to develop if teachers are supported in real or virtual interactions, centred on actual experiences but also incorporating an understanding of Science which shows scientists as people asking and pursuing questions in different ways.

A common reservation is that examination performance would suffer if time is given to activity which is seen as non-essential. Accounts from practicing teachers who achieve both good examination results and a high level of pupil engagement in Science – enjoyment, satisfaction, further study of Science – may be important in persuading teachers that examinations and inquiry are not polar opposites but reconciliable responsibilities of teachers and elements of good teaching in Science. There is scope for the development of indicators that may be used formatively by teachers for this purpose (Scepsati and Inquiract are examples of instruments developed in this WP5 – see Blake et al, 2010)

Section 6: Scientists talking about their science

Some quotations from Scientists have been included in this paper. This could be further extended within a website and also include currently active scientists, using video clips of interviews. For example, a Strathclyde research scientist working on the Linking of Renewable Energy Sources into Power Networks remarked that often it was 'learning as you go … (that the work) … is a bit non-linear … (sometimes … you are just doing stuff …seeing what happens …you try something, it fails, you talk to someone else…you come across a good paper… you go back to the theory'. A project might start with saying 'let's put panels on people's roofs and see what we get … (leading to) … why don't we change the tariffs and observe results of that? …different things, ideas have to be tried out … with solar panels the energy is affected by clouds, dirty rain, degradation of panel materials, wavelength of light'. We could build more examples of this not just in text from interviews but in video clips of then at their work.

Section 7: Being realistic

There is clearly greater scope for extensive support in post-qualification CPD. Within ITE, there is an opportunity right at the start to introduce new teachers to inquiry and to at least lay the foundations for the development of good practice. However the difficulties have to be recognised. The demands from the policy makers, schools themselves and of course student teachers with immediate concerns about qualifying are all realistic and relevant. The developm,ent of the website as a universally accessible resource with links to other valuable sources would eb a priority. Structured input would have to be limited and manageable, so a minimum recommendation might be a package which incorporates:

introductory lecture

practical workshop session

protected experience of teaching investigatively

small assignment requiring reflection on the experience

2/3 seminars introducing perspectives on the nature of science, history of scientific ideas, biographies of scientists

set of required readings introducing theoretical perspectives

A final thought on the recruitment of students:

> The disciplines of science and technology are often perceived as being difficult, and the results obtained by pupils are frequently used as selection criteria – a worrying phenomenon for both pupils and their parents. Better educational methods are necessary to overcome these obstacles and to convince them of the positive intrinsic value of science and technology, and the jobs associated with this field. **However, teachers are often recruited on the basis of their specific competence in certain subjects and not on the basis of their teaching ability (Sgard, 2007).**

References

Blake, Allan et al, (2010) SCEPSATI (Science Classroom Environment Pupil Satisfaction & Achievement Instrument) & INQUIRACT, Glasgow, University of Strathclyde (available from www.ntnu.no/s-team).

Gribbin, J. (1998) *In Search of Schrödinger's Cat: Quantum Physics and Reality*, London: Black Swan.

Hodson, Derek, (1999) Building a Case for a Sociocultural and Inquiry-Oriented View of Science Education, *Journal of Science Education and Technology*, 8/3. 241-249.

Kirschner, Paul A., Sweller, John & Clark Richard E, (2006) Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching, *Educational Psychologist*, 41/2, 75–86.

McNally J. (2006) Confidence and Loose Opportunism in the Science Classroom: Towards a pedagogy of investigative science for beginning teachers *International Journal of Science Education* 28/4, 423–438.

Roth, Wolff-Michael (2002) *Authentic school science: knowing and learning in open-inquiry science*, Dordrecht, Kluwer Academic Publishing.

Sgard, Frédéric (2007) 'Communication' in *Research EU Special issue of the magazine of the European Research Area* (p.19) available at: http://ec.europa.eu/research/research-eu/special_education/03/article_edu19_en.html

S-TEAM Product 8.1 (Preliminary version): overview report on the use of scientific literacy in Teacher Professional Development

The WP8 Team

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.

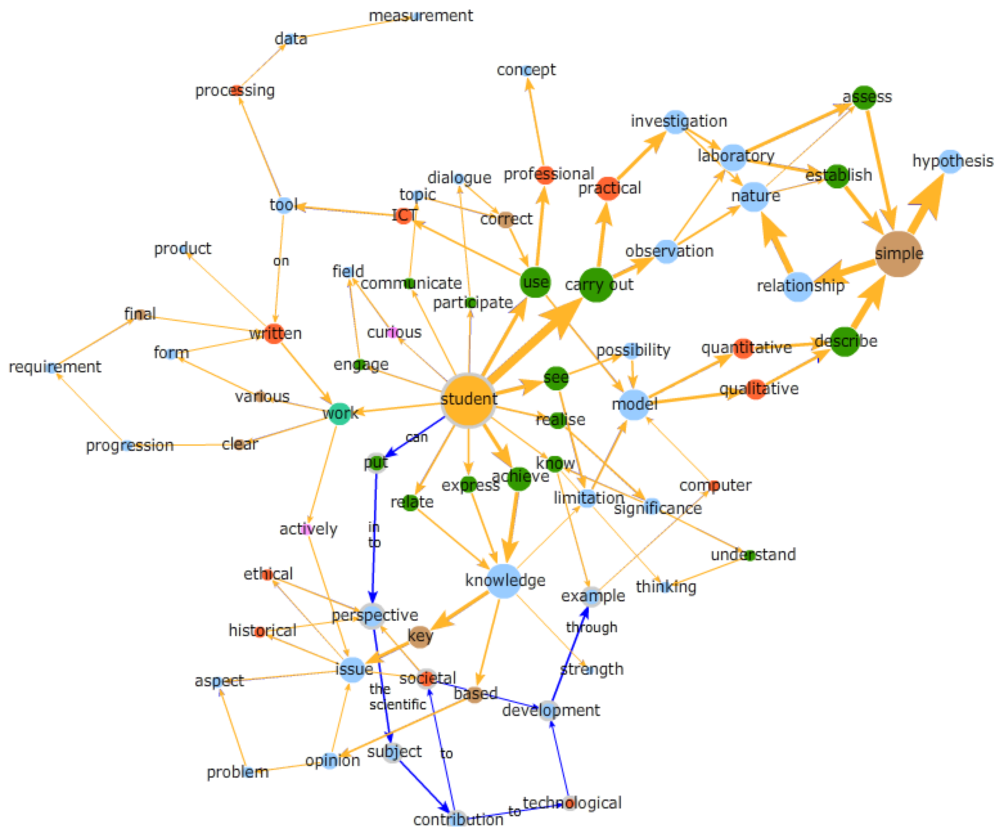


Figure 1. The text of Danish Scientific Literacy is represented in this concept map. For clarity, the path of each sentence from the original text is highlighted in blue when a cursor is moved over it.

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).

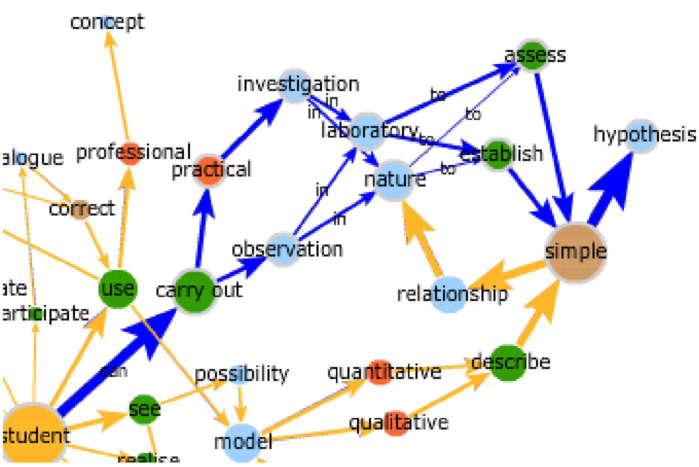


Figure 2. Detail from the Danish map of Scientific Literacy with the student goals associated with 'carry out' highlighted in blue.

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 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 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[13]

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

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

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 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.

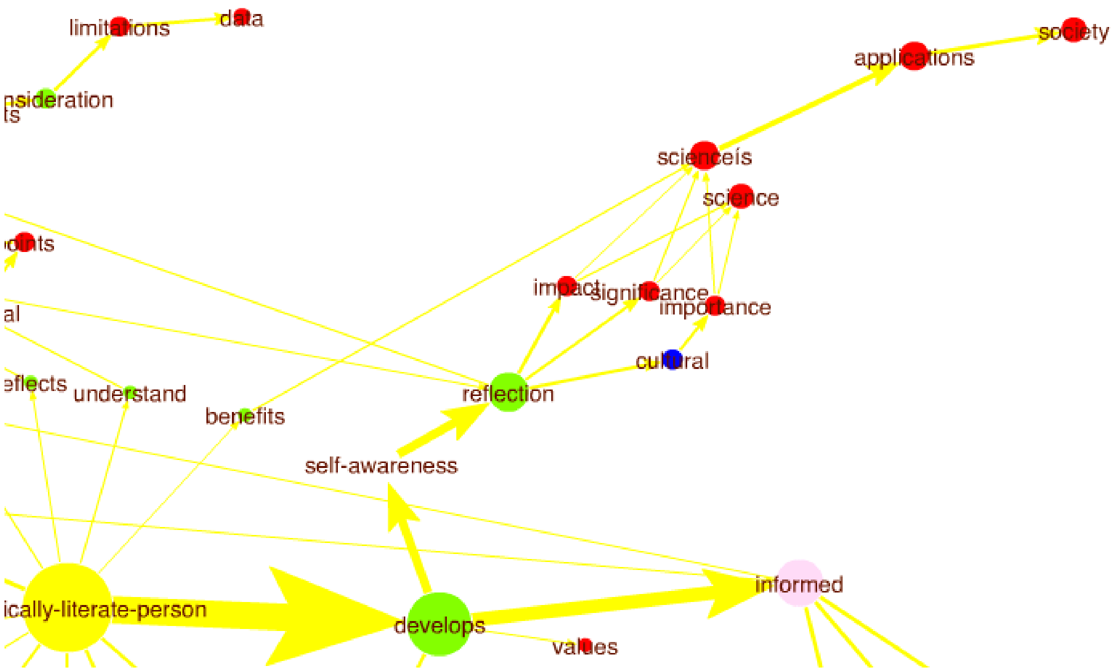


Figure 3. Detail from the Scottish national statement of Scientific Literacy.

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'.14 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.

[14] 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 4). 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.

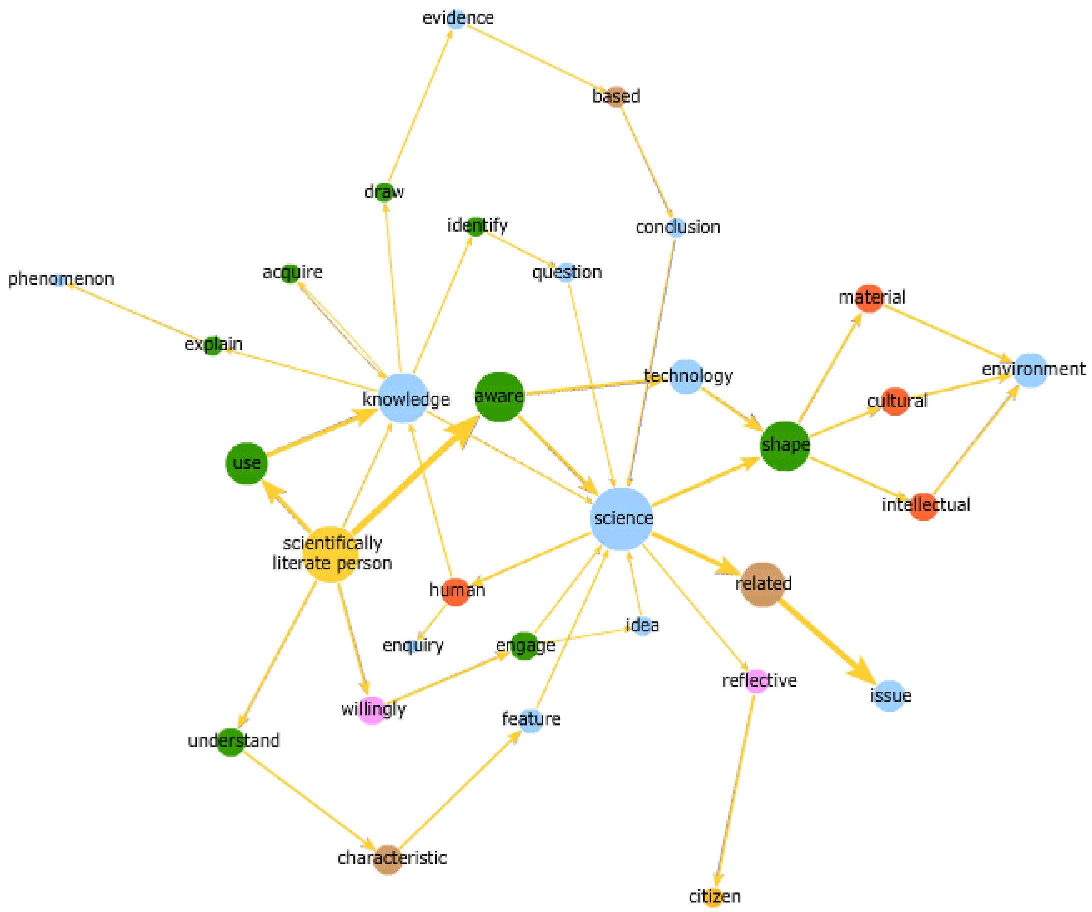


Figure 4. PISA 2006 statements of Scientific Literacy.

References

Czerniak, C.M. (1990). *A study of self-efficacy, anxiety, and science knowledge in pre-service elementary teachers.* A paper presented at the annual meeting of the National Association of Research in Science Teaching, Atlanta, GA.

EU (2010). Key competences for lifelong learning (Retrieved at http://ec.europa.eu/education/lifelong-learning-policy/doc28_en.htm April 2010)

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

Kress, G.R. (2003). Literacy in the new media age. London: Routledge Falmer

Kress, G. and Van Leeuwen, T. (1996) *Reading Images: The Grammar of Visual Design*. London: Routledge.

Smith, C., Kelly, F. & Mackenzie, S. (2010). *A teaching tool for supporting scientific thinking through investigations and other teaching methods.* Written for S-Team Workpackage 5. University of Strathclyde Education.

Postscript: 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.
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 seek 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.

Table 1: Aspects of scientific thinking[15]

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.

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

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

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!

References

Cameron, L. (2002) Metaphors in the Learning of Science; a discourse focus. British Educational Research Journal, 28(5), 673-688

Dunbar, K. and Blanchette, I. (2001) The in vivo/in vitro approach to cognition: The case of analogy. *Trends in Cognitive Science, 5(8)*, 334-339

Gibbs, Jr., R.W. *The Poetics of Mind: Figurative though, language and understanding*. Cambridge: Cambridge University Press.

Lakoff George & Johnson, Mark (1999) *Philosophy in the Flesh: The embodied mind and its challenge to Western Philosophy*, New York, Basic Books

Lakoff G and Johnson M (1980) *Metaphors We Live By*. Chicago: University of Chicago Press.

Smith, C., Kelly, F. & Mackenzie, S. (2010). *A teaching tool for supporting scientific thinking through investigations and other teaching methods.* Written for S-Team Workpackage 5. University of Strathclyde Education (in this document, pp.

Sutton, C. (1992) Words, Science and Learning. Buckingham: Open University Press

WP8 (2010) WP8 Overview On The Use of Scientific Literacy in Teacher Professional Development. Written for S-TEAM Workpackage 8, University of Copenhagen (in this document, pp.

.

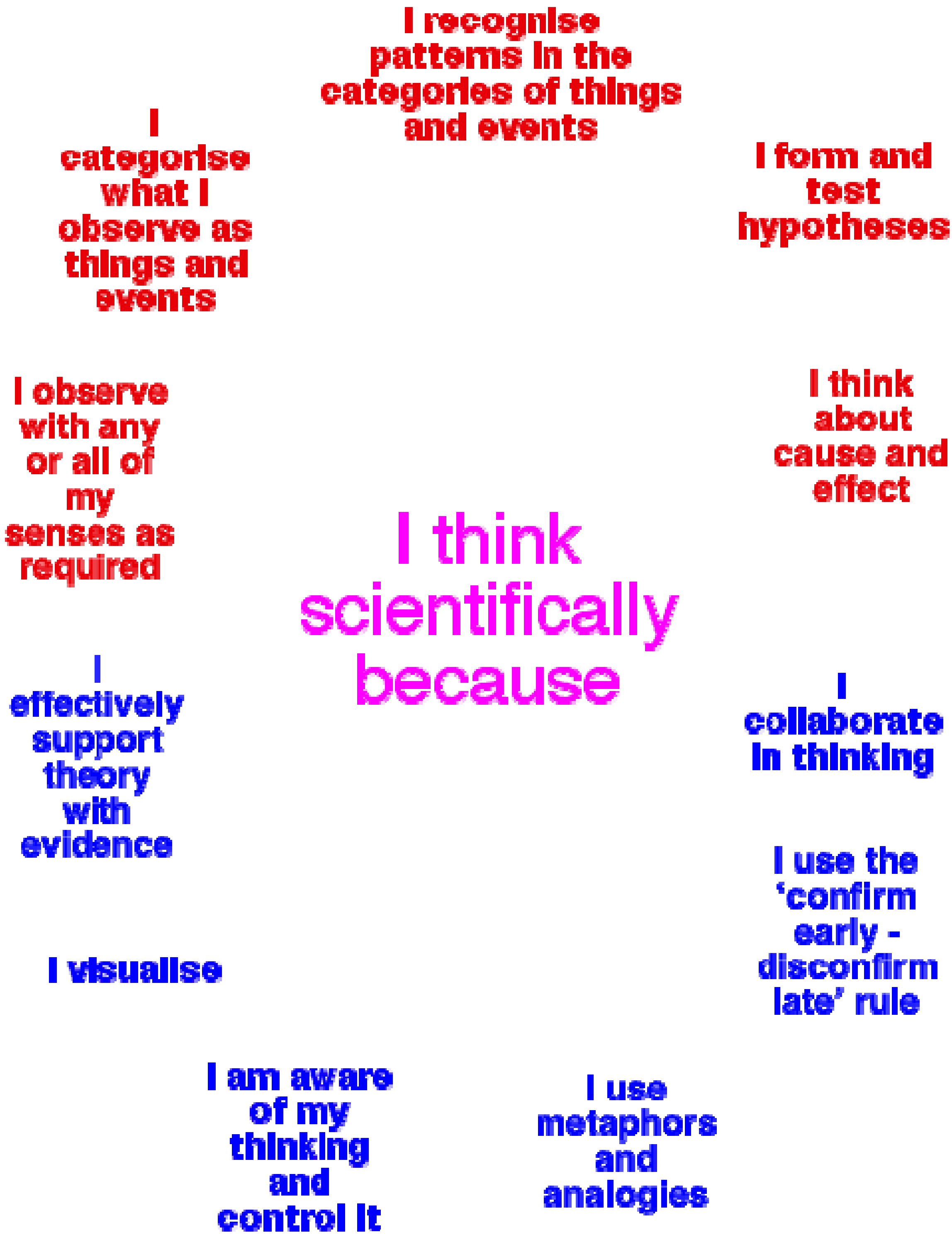
Support for scientific thinking in school science investigations: A Teaching Tool

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'	In practice, this may be rarely used in school

heuristic	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[16], 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

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

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 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.

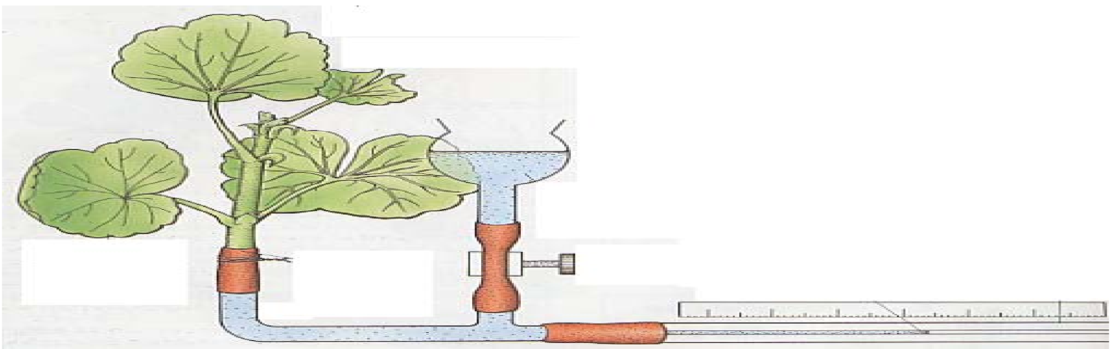


Figure 2: A bubble potometer that can be used to investigate evaporation of water from leaves.

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.

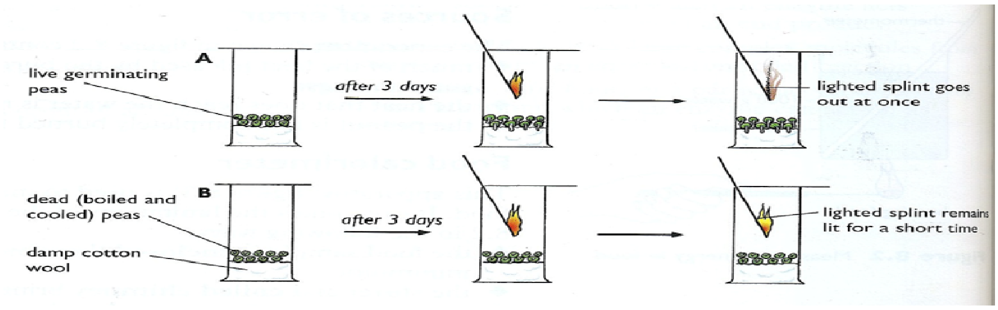


Figure 3: Oxygen uptake (Torrance, 2001, page 72)

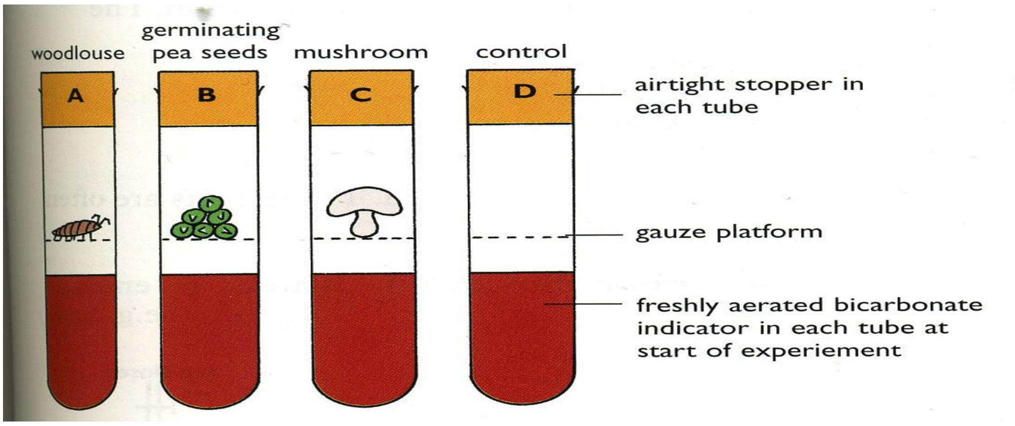


Figure 4: Release of Carbon dioxide in respiration (Torrance, 2001, page 73)

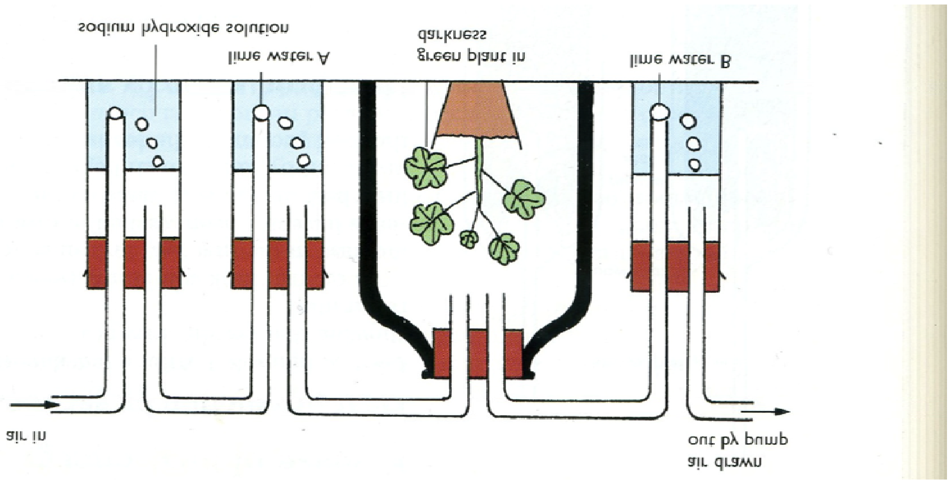


Figure 5: Release of Carbon dioxide by green plants (Torrance, 2001, page 73)

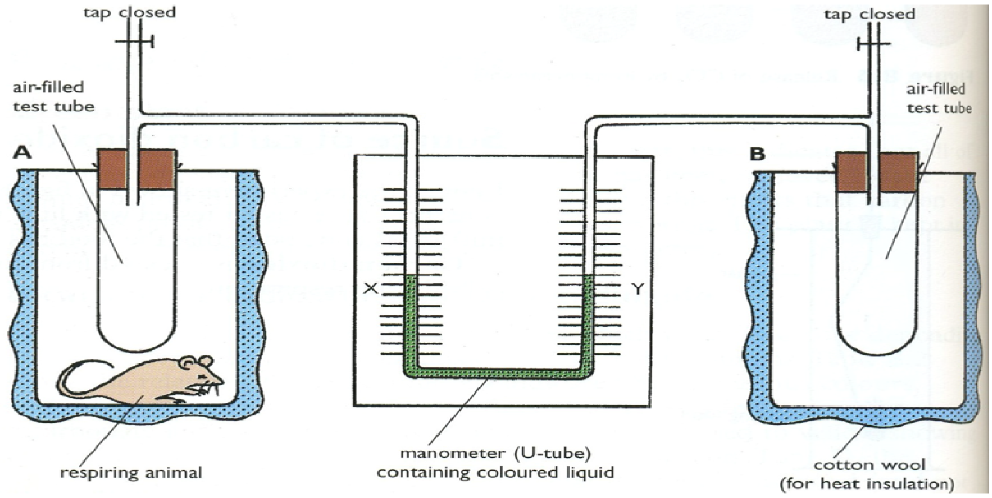


Figure 6: Release of heat by respiring animal (Torrance, 2001, page 74)

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-disconfirm late' heuristic	Not supported

	I collaborate in thinking	These experiments tend to be teacher led, so this would depend upon the quality of interaction.

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

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

investigation.		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	Aspects of scientific	Analysis

Investigation	thinking)	
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-	unsupported

	disconfirm late' heuristic	
	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.

References

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

Smith, C.A. (2010) (With additional material supplied by Kelly, F and Mackenzie, S). Thinking pedagogically about scientific thinking: Towards a taxonomy of investigations**.** S-TEAM Conference, Nottingham. January, 2010. Available at: www.ntnu.no/s-team

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	.

Contributors to Deliverable 6a

Zozan Kaya Asphaug has an MA in International Relations and an MSc in European Government and Politics from London School of Economics (LSE). She has work-experience from several NGO's, from the Norwegian Ministry of Foreign Affairs, and as research assistant and researcher at LSE and the Norwegian University of Science and Technology (NTNU).

Gultekin Cakmakci, is a Lecturer at Hacettepe University, Ankara, and teaches courses on science education. His research interests focus on developing scientific literacy among students/teachers, and on the design, implementation and evaluation of science teaching.

Jens Dolin, Associate Professor, is the WP8 leader and head of the Department of Science Education at the University of Copenhagen. He has done research in teaching and learning science, with a focus on dialogical processes, forms of representation and the development of competencies.

Robert Evans is Associate Professor in the Department of Science education, University of Copenhagen, and is assistant WP8 leader. His international research in personal capacity beliefs has focused on understanding factors affecting new science teachers and devising programs of support for them.

Liselott Forsman, is a teacher educator and action researcher at Abo Akademi University in Vasa, working with the competence of teachers to support the learning of all students in the multicultural classroom, She has an interest in making teacher education itself more investigative, through the use of action research principles.

Peter Gray is the project manager for S-TEAM and has worked on various national and European projects on teacher education and vocational education. His research interests are spatiality, conversation and European collaboration.

Florence Le Hebel is an associate professor in Geology at University of Lyon. Her projects focus on students' attitudes and motivations related to science in school and outside school.

Doris Jorde is a professor in Science Education and Vice Rector of the University of Oslo and is currently deputy coordinator of the S-TEAM project. After completing her doctorate at the University of California, Berkeley, she moved to Oslo where she has worked with developing science education as a research field. She was the project leader of Viten.no and led the project "Mind the Gap" – a European initiative to improve the teaching of science through inquiry based teaching strategies.

Fearghal Kelly is a Biology Teacher who is currently seconded as a Development Officer for The Curriculum for Excellence in Scotland. He is also a member of the Reference Group for S-TEAM.

Berit Kurtén-Finnäs, is a teacher educator and leader of the Resource Centre for Chemistry Didactics at Abo Akademi University in Vasa. She defended her doctoral thesis in 2008 on the use of open investigations and V-heuristics in grade 7.

Sinclair Mackenzie is a Physics Teacher with Highland Region in Scotland. He is also a member of the Reference Group for S-TEAM. Additional information available at http://blog.mrmackenzie.co.uk/2008/04/07/is-there-really-dead-time-in-the-school-year/

Jim McNally is Head of Department of Curricular Studies and a Chair in the field of Teacher Education at Strathclyde University. Jim was a former teacher in Scottish secondary schools. His research interests are teacher Development, teaching investigative science and building grounded theory.

Peter van Marion is Professor in Science Education at NTNU. His main interests are in outdoor work in biology, practical work in science and environmental education. He is the author of text books in Science for grade 12. Currently he is the Director of the University's Resource Centre for Mathematics, Science and Technology Education

Pascale Montpied is a senior researcher in neurobiology at the CNRS-UMR ICAR-COAST, Université Lyon 2 with more than 20 years of experience in this field and has been a researcher in science education for 3 years. She carries out research on motivation and is currently working on pupils' interests and culture in sciences.

Sonja. M Mork was awarded her doctoral thesis in January 2006 with the title *ICT in Science Education. Exploring the digital learning materials at viten.no.* She now works with classroom studies on teaching and learning in science at the Norwegian Centre for Science Education, where she also continues research on materials from viten.no.

Anna-Lena Østern is professor of arts education at NTNU, Trondheim. Her current research is on aesthetic approaches to education, and multimodal literacy She is leader of NAFOL, the Norwegian National Post Graduate School in Teacher Education.

Ran Peleg is a Ph.D. student at the Department of Education Technion, Israel, in Technology and Science, and an active performer and producer of Science Theatre. He investigate ways in which theatre and drama can be utilized as an educational tool for science teaching in order to enhance scientific literacy and positive attitudes to science.

Colin Smith is a retired Biology Teacher who is currently working as a Research Associate on Work Package 5 of the S-TEAM Project. He has previously worked as a teacher-researcher on a project looking at the early professional learning of teachers (EPL Project) and has worked with teachers in his own school in using research to develop practice.

Alex Strømme is Professor in Science Education at NTNU, Trondheim, works with teacher training in biology. He has worked for many years with ICT in schools and universities. He has developed, and carried out research on, web-based programmes in science.

Acknowledgements

We would like to thank Hilde Roysland, our project administrator at NTNU, for final preparation of this document, and Professor Geir Karlsen for his leadership and inspiration.

S-TEAM Partners

ISBN 978-82-93118-04-6

Cyprus	• European University – Cyprus *
Czech R.	• University of South Bohemia *
Denmark	• University of Copenhagen *
	• Aarhus Universitet
Estonia	• University of Tallinn *
Finland	• Abo Akademi University
	• Helsinki University *
	• University of Jyväskylä
France	• Centre National de la Recherche Scientifique
	• Université Pierre Mendes-France *
	• Université Rennes 2 – Haute Bretagne
Germany	• Friedrich Schiller University of Jena (1)
	• Leibniz Institute for Science Education at the University of Kiel *
	• Technical University Munich (2)
Israel	• Technion – Israel Institute of Technology *
Lithuania	• Kaunas University of Technology *
	• Vilnius Pedagogical University
Norway	• **Norwegian University of Science and Technology (coordinator)**
	• University of Oslo *
Spain	• Universidade de Santiago de Compostela *
Sweden	• Mälardalen University *
Turkey	• Hacettepe University *
	• Gazi University
UK	• University of Bristol *
	• University of Leeds
	• University of Strathclyde *

* National Liaison Partner

(1) To March 2010

(2) From April 2010

S-TEAM FIRING UP SCIENCE EDUCATION

SEVENTH FRAMEWORK PROGRAMME