INTERNATIONAL TECHNOLOGY EDUCATION SERIES

Professional Development for Primary Teachers in Science and Technology

The Dutch VTB-Pro Project in an International Perspective

Marc J. de Vries, Hanno van Keulen, Sylvia Peters and Juliette Walma van der Molen (Eds.)

Foreword by Michel Rocard

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Professional Development for Primary Teachers in Science and Technology

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Scope
Technology Education has gone through a lot of changes in the past decades. It has developed from a craft oriented school subject to a learning area in which the meaning of technology as an important part of our contemporary culture is explored, both by the learning of theoretical concepts and through practical activities. This development has been accompanied by educational research. The output of research studies is published mostly as articles in scholarly Technology Education and Science Education journals. There is a need, however, for more than that. The field still lacks an international book series that is entirely dedicated to Technology Education. *The International Technology Education Studies* aim at providing the opportunity to publish more extensive texts than in journal articles, or to publish coherent collections of articles/chapters that focus on a certain theme. In this book series monographs and edited volumes will be published. The books will be peer reviewed in order to assure the quality of the texts.

Professional Development for Primary Teachers in Science and Technology

The Dutch VTB-Pro Project in an International Perspective

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MICHEL ROCARD[i]

FOREWORD

In this beginning of the XXIst century, we seem to have many reasons to worry about the future: climate heating, financial disequilibrium, nuclear proliferation among others. . .

Let me call the reader's attention on another one, less visible and more forgotten, but more capable to produce some optimism when looked at, and treated: it can be remedied.

I am thinking here to this long term, slow and regular tendency which conducts in most developed countries boys and even more girls at school to choose scientific studies in a declining percentage. This evolution is threatening, for the future, for our competition position in front of emerging countries and especially China. The answer is to be found in deep changes and improvements in the way mathematics and sciences are taught.

In the Report I presented to the European Commission in 2007, Science Education Now: a Renewed Pedagogy for the Future of Europe, we stressed the fact that teachers are key players to renew science education, especially in primary schools. I was pleased to see the large impact of this Report, not only in the funding decisions taken by the Commission, but primarily in the numerous initiatives, experiments and creative projects which began to flourish in Europe. Besides, we observe an increasing involvement of the scientific community, which follows the pioneering path traced by Georges Charpak.

Among these many successful initiatives, I have been pleased to discover the VTB-Pro three-years project carried out in the Netherlands (Broadening technological education in primary school). Focusing on professional development of teachers and presenting first hand testimonies and research, the present book demonstrates how to deal with this issue, so critical for a renewed pedagogy. With proper methods, the knowledge of science, the interest in science and technology, the pedagogical skills can all be improved among teachers who often have no or little affection for science.

I congratulate the authors of this book and I hope that the new European strategy Europe 2020 will keep supporting such creative ventures, which are so important for our common future.

NOTES

[i] Michel Rocard is a former French Prime Minister and was also a member of the European Parliament. He chaired the High Level Group on Science Education that produced the report Science Education Now: a Renewed Pedagogy for the Future of Europe (European Commission, 2007).

MARC J. DE VRIES, HANNO VAN KEULEN, SYLVIA PETERS, AND JULIETTE H. WALMA VAN DER MOLEN

PREFACE

This book is the outcome of a major project on science and technology in primary education in the Netherlands that ran from May 2007 till December 2010. The project aimed at providing professional development to Dutch primary teachers in order to enable them to implement new activities in their curriculum that focus on science and technology. The name of the project was: VTB-Pro. VTB stands for Verbreding Techniek Basisonderwijs - Professionalisering, in English: Broadening Technological Education in Primary Education – Professional Development. A substantial part of this project was dedicated to educational research. This book contains a selection of research studies that have been conducted in the context of this project. As the themes that are dealt with in the research go beyond the specific situation in the Netherlands, this book is truly a publication that is of interest for an international readership. To emphasize this, we have asked two experts of international reputation to write the first chapter. Wynne Harlen (University of Bristol) and Pierre Léna (Université Paris Didérot) were prepared to do this.

The VTB-Pro project was related to the VTB project in which the introduction of science and technology activities in primary education was the main goal. This project was at school level. But it is well known that in order to make this introduction a success, teachers need to be well prepared for it. This is by no means obvious when it comes to science and technology in primary education. The large majority of primary teachers have no affection for science and technology. To the contrary, they often became primary teachers in the expectation that they would not need to be involved in that. Often, the mere thought of having to teach science and technology makes them feel quite uncomfortable. That is why the VTB-Pro project was initiated: as a response to this problem. The purpose of the VTB-Pro project was to create favourable conditions for primary science and technology education by helping primary teachers to acquire the necessary knowledge, skills, attitudes and pedagogy for teaching science and technology. The professional development activities and the research in this project were developed and conducted by consortiums of primary teacher training institutes and universities. These were organised in what was called ‘Knowledge Centres’, of which there were five in the country. A Project Management group was responsible for the organisation of the project; a Programme Council was installed to guard the scientific quality of the project. Two external assessment organisations were hired to monitor the project.

The VTB-Pro project was guided by a theoretical framework that described what primary teachers needed to know and be able to in order to implement science and technology in their classroom practice (Walma van der Molen, de Lange, & Kok, 2007). Three main elements were identified:

1. Science- and technology-related knowledge and skills
2. Favourable attitudes towards science and technology, and
3. Pedagogical skills for inquiry-based learning and learning-by-design.

These three elements formed the basis of the professional development activities, but also of the research part in the project. This is reflected in the structure of this book. Part I is about the first strand in the VTB-Pro research programme: knowledge and skills. In this part there are both studies on what knowledge and skills are desirable from a social and educational point of view and studies on what primary teachers already know and are able to. Part II is on attitudes. The studies in this chapter range from instrument development to identifying the actual attitude teachers have. Part III deals with concept learning and language development as the two main domains that have been studied in the context of the Pedagogical Content Knowledge for primary science and technology education. Studies in this part investigate to what extent the professional development activities have resulted in teachers acquiring this type of expertise. Part IV focuses on the nature of the professional development activities themselves: what makes such activities successful? Each of these Parts is further introduced in a separate chapter, one for each Part.

We want to thank all authors for their cooperation in this effort. In particular we want to thank Wynne Harlen and Pierre Léna for their input. We still have very positive remembrances of the meeting of us as the editors of this book with the two of you in Pierre's institute in Paris. We also want to thank Sense's Peter de Liefde for offering us the opportunity to present the outcomes of the VTB-Pro project in the International Technology Education Studies series. We hope this volume will prove to be a worthy addition to this successful series.

WYNNE HARLEN AND PIERRE LÉNA

1. INTRODUCTION TO THE THEME

INTRODUCTION

There is concern in many countries of the world and throughout Europe that there is a decline in young people's interest in studying science, technology and mathematics (European Commission 2007, OECD 2008a). The blame for this state of affairs is laid mainly at the door of teaching methods which have presented science as being a matter of facts and theories that seem to have little relevance to students' everyday lives. It is not surprising that alternative areas of study, in the arts and humanities for instance, appear more attractive to students living in a fast-moving, media-rich world.

However, the impact on the supply of future scientists and technologists is not the main issue; rather it is the importance of ensuring that all children derive from their education an understanding of scientific ideas, of how science works and of science as part of culture. In other words, what is required is a science education that engages and informs everyone; not just future scientists and technologists.

In today's world, science – understanding phenomena in nature – and technology – using this knowledge to design and make products for the use of mankind – overlap to such a degree that it seems difficult for education to consider only the former, despite differences in their epistemological status and possibly in their learning process. Both are therefore considered throughout this book, although this introductory chapter has a stronger focus on science.

Providing science education for all students is a considerable challenge; it forces attention to a range of questions about the content, the pedagogy, the role of assessment, how teachers are prepared for teaching science and where science education should start. These are questions with which we are concerned, but since the focus is on primary education it is important to have sound reasons for beginning science education at the very start of schooling.

WHY START SCIENCE IN THE PRIMARY SCHOOL?

In the 1960s, projects developing science in the primary school were begun in the United States (ESS, SCIS, SAPA) and in the United Kingdom (Nuffield Junior Science, Science 5/13) and spread to other countries, notably Africa (SEPA). The reasons given for these developments half a century ago are still relevant today. In

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addition to the need for more scientists, the main reasons were the need for everyone to:

- be able to relate to the rapid changes that science and technology make to the world around
- share in understanding and celebrating science as an important human achievement.
- know how to approach problems by seeking relevant information and basing decisions on evidence.

Since that time, further strong reasons have been added to the case through increasing attention to research into children's learning. Research into the ideas of young children, inspired by the work of Jean Piaget, was carried out in France by Guesne (1973) and Tiberghien and Delacôte (1978). Similar work by Driver (1973, 1983) and others, conducted with secondary school students, revealed that older students' ideas about scientific aspects of the natural world were at odds with the scientific view that secondary teachers assumed them to have.

From the early research, in which students were interviewed individually by strangers, there developed methods which enabled more systematic investigation and the use of quantitative as well as qualitative methods of analysis. Larger scale studies into primary children's ideas began with studies in New Zealand (Osborne and Freyberg 1985). In the UK the Science Processes and Concept Exploration (SPACE) project revealed a range of ideas about the scientific aspects of their surroundings that children had developed from their limited experience and ways of thinking (SPACE Research Reports 1990 – 1998). It was clear that these ideas could not be ignored; children believed them, had worked them out for themselves, and indeed it was clear that these pre-existing ideas had to be the starting point from which more scientific ideas could be developed.

Thus a further argument was added to the case for science in the primary school, that children's ideas about the natural world are developing throughout the primary years whether or not they are taught science. Without intervention to introduce a scientific approach in their exploration, many of the ideas they develop are non-scientific and if they persist may obstruct later learning.

Since then, other research has added to the importance of starting science early:

- Attitudes towards science develop in the pre-secondary years, earlier than attitudes to some other school subjects. This was first reported by Ormerod and Duckworth in 1975, but more recently research evidence reported by The Royal Society (2006, 2010) and by the French Académie des sciences (Charpak *et al* 2005) shows that most children develop interests and attitudes towards science well before the age of 14 and many before the age of 11.
- Studies made on renowned scientists or engineers have shown that their deep interest for science arose as early as age 6 or 7, and was often encouraged by parents or teachers (Guichard 2007).
- Gender differences in academic performance, which continue to be of concern in science education at higher levels, have not appeared at the primary stage (Haworth *et al* 2007, Royal Society 2010).

- At the primary level there is no correlation between attitudes to science and science achievement, so primary children can feel positive about science regardless of their level of achievement (Royal Society 2010).

Benefits of an early start to science education

How early could early be? Observations made on infants (Gopnik *et al* 1999, Dehaene-Lambertz *et al* 2008) indicate that making sense of their experience of the environment characterises the development of cognition from a very early age. With an appropriate pedagogy, science education can begin as early as at the age of 5 in preschool, as numerous experiments have demonstrated (Duschl *et al* 2007, Fleer 2007).

There are benefits of starting science in the primary school for the children themselves and for society. For children it helps them to understand aspects of the world around them, both satisfying and stimulating their curiosity. By learning to investigate and inquire they realise that they have the capability of answering some of their questions. Challenging each other, and being challenged, to say 'how do you know that...', as children frequently do, they begin to recognise the importance of having evidence to support claims. The benefits to society follow from young people developing understanding of key ideas that enable them to make informed choices both as children and later in life about, for instance, their diet, exercise, use of energy and care of the environment. Equally the development of scientific skills and attitudes supports a growing appreciation of the role of science in daily life.

The research clearly indicates that unless children's intuitive non-scientific ideas are addressed through appropriate primary science education, these benefits are less likely to be realised.

THE GOALS OF PRIMARY SCIENCE

Deciding what is 'appropriate primary science education' should start from considering the understanding, skills and attitudes we want primary school children to develop. Taking into account how children learn then leads to identifying the kinds of experiences that are likely to help that learning at various stages. To achieve the understandings that justify beginning science in the primary school it is apparent that we must be concerned not only to help them to gain knowledge of how things in the natural world behave, but also how this knowledge is achieved. This means developing both ideas *of* science and *about* science.

Science here means the natural sciences, and does not include mathematics. Although modern science would not exist without mathematics, it is fortunate that learning science at the primary level can be pursued without the need of formulae, using a great many qualitative observations with only a modest use of quantitative data. This does not mean that many of the inquiry principles developed in this book could not equally inspire mathematics education (Artigue 2010), nor that science and mathematics should be taught entirely independently.

Ideas of science

Considering first the ideas *of* science, primary school experiences have to serve both to enable children to understand and to enjoy finding out about the natural world around them today and to begin their understanding of the broad generalisations that will serve them in their later life; it has to benefit both the present and the future. We find it useful to describe the relationship between the ideas young children develop from exploration and observation of their immediate surroundings and the more abstract generalisations that enable understanding of a wide range of phenomena in terms of 'small' and 'big' ideas. For example small ideas are those that children might form through exploration of living and non-living things about the essential characteristics of organisms. These ideas form a basis for later understanding of how the functions of organisms can be explained in terms of their cellular composition. Similarly, finding that pushing and pulling things can make them move is a small idea that makes a contribution to a more general understanding of the relationship between movement of objects and the forces acting on them.

As children grow and expand their experiences they should be helped to link related small ideas together, gradually forming bigger ideas, constituting a progression in learning from the particular to the more general and abstract. This is not to limit the inquiries of young children to certain phenomena and events that lead to big ideas but rather to highlight the importance of constructing the broader understandings needed for scientific literacy by linking together smaller ideas. In other words, a big idea is not a collection of small ones but is built from them.

Ideas about science

Inclusion of ideas *about* science among the goals recognises that children encounter many facts, ideas and claims that purport to be scientifically based. It is important for them to develop the ability to evaluate the quality of this information, for otherwise they are powerless to resist claims based on false evidence or no evidence at all. Such evaluation requires an understanding of the ways of collecting, analysing and interpreting data to provide evidence and of the role of evidence in arriving at scientific explanations.

As with ideas of science, there are big and small ideas about science. For example, a big idea would be that 'science is a search for explanations which fit the evidence available at a particular time but may be changed if convincing conflicting evidence is found'. This level of abstraction is beyond primary children but, in trying to explain an observation, they can take a step towards this idea through becoming aware of the difference between, on the one hand, a guess at what causes a certain effect and, on the other, proposing a cause that is supported by evidence. In practice the best way to come to understand how science works is by participation, by children undertaking scientific inquiries of different kinds in which they have to decide what observations or measurements are needed to answer a question, they collect and use relevant data, they discuss possible explanations and then reflect critically on the processes they have carried out. In this way they develop understanding of the role of these skills in proposing explanations of events and phenomena.

Skills

Developing ideas about science requires knowledge of the skills involved in science inquiry. A further goal of science education is to complement this knowledge with the ability to use the skills in conducting investigations. This requires the ability to

- raise questions that can be answered by investigation
- develop hypotheses about how events and relationships can be explained
- make predictions based on the hypotheses
- use observation and measurement to gather data
- interpret data and draw valid conclusions from evidence
- communicate, report and reflect on procedures and conclusions.

Providing the subject matter is familiar, there is a discernible progression in the development of the skills. For example, children are likely to begin to 'interpret data and draw valid conclusions from evidence' by simply comparing what they find with what they expected or predicted. This matures into drawing conclusions consistent with all the evidence available and eventually to recognising that any conclusions are tentative and might be change by new evidence.

The last of the skills listed above connects with children's development of language, a corner stone of primary education underpinning learning across the curriculum. In the case of science, language is central to the development of understanding and at the same time its development benefits from the interaction with things and people that is the core of scientific activity. Naming objects enables them to be described and discussed in their absence; grouping and classifying according to criteria leads to development of concepts; expressing cause and effect requires the careful use of connecting words and of tenses. Some words used in science ('energy', 'work', 'animal' for instance) have particular meaning in science, more precise than their use in everyday speech. It is not possible to prevent the everyday usage, but children need to know when such words are being used strictly with their scientific meaning.

Chapters in Part 1 of this book take up the discussion of the ideas and abilities required for scientific literacy. But it would not be appropriate to leave the subject of goals without including reference development of attitudes.

Attitudes

Attitudes are generally taken to be 'potentially important determinants of behaviour, describing the state of being prepared or disposed to act in a certain way in relation to particular objects' (Royal Society 2010). It is useful to distinguish between attitudes that apply within scientific activity (scientific attitudes) and those that apply in relation to taking part in or having an affective response towards scientific activity (attitudes towards science). Attitudes of the former kind include openmindedness in collecting and interpreting data, being prepared to change or modify ideas in light of new evidence, and behaving responsibly in conducting investigations. Claims about attitudes of the second kind need to be treated with caution since they are generally derived from self-report of liking for the subject or for specific activities, rather than from observations of behaviour during scientific activities. Moreover, there is evidence that an affective response is not so much associated with the whole subject as with specific topics or activities, mediated by the self-concept as someone who is good or not good at science (Russell et al 1988, Martin 2010).

Attitudes of both kinds, towards the subject and within the subject, are not developed in the same way as scientific ideas and skills. They exist in the way people behave and are communicated largely through behaviour; they are 'caught' rather than 'taught', with implications for teachers to which we return later. Neither is there quite the same type of progression in developing attitude as in the case of ideas and skills. Indicative behaviours of attitudes are accumulated and depend more on experiences that foster them than on age or stage.

LEARNING EXPERIENCES IN PRIMARY SCIENCE

In order to identify the most fruitful learning experiences that will enable the goals of primary science to be achieved we must first consider what is known about how children learn. Information from research into children's learning leads to the following conclusions:

- Children are forming ideas about the world around them from birth and will use their own ideas in making sense of new events and phenomena they encounter
- Real understanding, rather than being received from others, is created by children in interaction with adults or other children
- Some of children's ideas are in conflict with the scientific views of things
- Language, particularly discussion and interaction with others, has an important role to play in forming children's ideas
- Direct physical action on objects is important for infants' learning, gradually giving way to reasoning which, at the primary level, is about real events and objects rather than abstractions. These experiences of real objects slowly lead to the construction of abstract notions, such as *velocity* or *energy.*

Neurosciences and learning

These conclusions from studies at the macroscopic level of behaviour are now confirmed by evidence at the microscopic level of brain activity. For example, studies of the activity in different parts of the brain when someone is engaged in various types of thought and action show that memory of events is aided when the original events are accompanied by talk, especially by conversation with adults who elaborate and evaluate the experience. Also, making notes or drawings helps in the solution of problems, particularly when attempting new types of problems involving several steps. It appears that such external representations can help offload some of the heavy demands upon working memory (Howard-Jones *et al* 2007).

Words are important because they represent objects or events, whilst being separate from the objects or events. This detachment of the symbol, the word, from what it represents enables the mental manipulation of experience, which is then no longer dependent on direct action. This representation is also essential to the development of metacognition – thinking about thinking – which is necessary for the development of control over mental processes, feelings and behaviour. According to Goswami and Bryant (2007) children can begin to gain awareness of their thinking and control behaviour in the later primary years. This enables them to improve their learning and memory by 'adopting effective cognitive strategies and by being aware of when they don't understand something' (p.14). The emergence of metacognition in the late primary years and continued increase in adolescence and adult life is consistent with findings about the nature and timing of the development of the brain (OECD 2007: 198).

Learning is influenced not only by the parts of the brain associated with cognition, but is also dependent on inner structures concerned with emotions. Excitement or anxiety causes stress and the release of chemicals in the brain which in turn release energy. Whilst excessive stress is damaging to cognitive functioning, as illustrated by recent research in China (Wei Yu 2010), at a level that it enables energy to be directed effectively in trying to understand new experiences or develop new skills, moderate stress may be positive, motivate learning and lead to the pleasure that comes from achieving a goal (Zull 2004). This supports the approach of finding what ideas and skills children have and using this information to give just the right amount of challenge for them to make progress. Engagement in learning depends on giving attention to certain stimuli, which depends on the brain's assessment of their importance to self identify, as made evident in attitudes to the subject.

A key message for science education from neurosciences is that the development of science concepts depends on the simultaneous activity in the visual, spatial, memory, deductive and kinaesthetic regions of the brain and in both hemispheres (Goswami and Bryant 2007). This indicates the need for a variety of different kinds of experience involving both physical and mental activity. It will involve being able to touch and manipulate objects, using language, linking to previous experience, reasoning, reflecting and interacting with others.

Implications for children's experiences

These considerations of learning lead to the conclusion that, in order to achieve the goals of primary science education, children should have experiences that:

- are a source of enjoyment and wonder, but at the same time enable them to develop their understanding of key ideas in science;
- concern real things in their experience that are seen by the children as relevant and appealing;

- build on their previous experience and pre-existing ideas, providing challenges within the reach of children so that they experience pleasure in learning;
- engage the emotions by making learning science exciting.

Over a period of time the activities should provide opportunities for

- developing skills of questioning, observing, measuring, hypothesising, predicting, planning controlled investigations, interpreting data, drawing conclusions, reporting findings, reflecting self-critically on procedures;
- talking to others, parents and the teachers about their ideas and activities;
- working collaboratively with others, considering others' ideas and sharing their own;
- expressing themselves, both orally and in writing, progressively using appropriate scientific terms and representations;
- applying their learning in real-life contexts.

Diversity among children

In view of globalisation and increased migration across cultural and national boundaries (OECD 2008b) it is important to ask: how universal are the requirements of children for learning science? In many developed or emerging countries school populations are highly heterogeneous, having different mother tongues, social groups, and economic, cultural and religious backgrounds. Such diversity broadens the category of children with special needs, a category often limited to the handicapped (OECD 2005). However, there are two factors which all children, no matter how diverse they are, have in common. First is their immediate perception of natural phenomena – the Sun and stars, water and air, falling stones, plants and animals. The laws governing these phenomena demonstrate the universality of science. Second is the universality of curiosity among children which, although less scientifically established, is empirically observed in classrooms throughout the world. Science education can build on these two factors to engage all children in a process of developing their scientific understanding, as has indeed been shown to be the case even for the most handicapped children (Centre Jean Lagarde 2006).

It is worth pointing out here that research in primary science education have shown little overall difference between boys' and girls' attitudes and performance, although there are differences in particular aspects, such as girls being better at writing plans for investigations and boys more willing to undertake practical investigations. (Russell *et al* 1988, Royal Society 2010). Obviously puberty will later introduce deeper differences, hence the importance of building up on a common ground before the age of 12-13.

It hardly needs to be pointed out that providing experiences listed above, however diverse the children are, is a task of considerable proportions; one which many primary teachers feel ill-prepared by their knowledge and skills to undertake effectively. The role of the teacher in this provision is so central that it deserves a detailed analysis, to which we turn in the next section.

A RENEWED PEDAGOGY

How will teachers choose activities of appropriate content and difficulty? Could it be by following a programme of activities that have been worked out by others and usually shown to 'work' for most children? Children are not all the same and following a pre-packaged course slavishly will inevitably mean that for some the experiences may be too distant to be understood or too familiar to challenge existing ideas.

However, finding activities to adopt or adapt is not the main problem in improving primary science education, particularly now that potentially useful activities are available in many countries for access from the internet (e.g. La main à la pâte 2010). Rather, what is required in many cases is a radical change in pedagogy. As the EC report cited at the start of this chapter suggests, what is needed is a greater use of inquiry-based methods. Although widely advocated across the world and in some cases for many years (NSF 1997, 1999; Michaels *et al* 2008; Harlen and Allende 2006, 2009) the spread is slow.

Ensuring that children have the kinds of opportunities we have argued are needed for real understanding requires a broad interpretation of inquiry-based science education. It is certainly more than children using skills for exploring and finding out; it is also more than providing first-hand experiences of materials and phenomena – even though these are important. It involves taking account of children's pre-existing ideas and promoting progression by adjusting challenge to match these starting ideas. In other words it shares elements of constructivist pedagogy and of formative assessment.

A broad meaning of inquiry-based science education

Inquiry-based teaching, as we would like it to be interpreted, shares with constructivism the importance of starting from children's ideas and sees the role of the teacher as providing children with the experiences, evidence and reasoning skills that will enable them to construct *scientific* ideas. Various strategies are available to teachers in this endeavour, such as extending experience, helping children to test ideas, linking ideas from one experience to a related one and involving children in seeking a range of ideas from various sources, importantly including discussion, dialogue and argumentation.

In recent thinking about learning, sharing and discussing ideas has been emphasised. There has been a perceptible shift away from the view that ideas are formed by individuals in isolation – that is, 'individual constructivism' – towards 'socio-cultural constructivism', which recognises the impact of others' ideas on the way learners make sense of things (Bransford *et al* 1999). This means a greater emphasis perhaps than before on communication through language, on the influences of cultural factors and on linking into a 'community of learners'.

Inquiry-based pedagogy shares with formative assessment the aim of developing understanding through learners taking charge of their learning. Formative assessment is a continuing cyclic process in which information about children's ideas and skills informs ongoing teaching and helps learners' active engagement in learning. It involves teachers gathering information about where children are in relation to the goals of their activities as part of teaching. This information is used in the identification of appropriate next steps and decisions about how to take them. It helps to ensure that there is progression by regulating teaching and learning to ensure the right degree of challenge to optimise progress.

Formative assessment, or assessment for learning, has been widely advocated in many countries since the review of research by Black and Wiliam (1998) showed that its use can raise levels of achievement. Among the key features is the active involvement of children in their own learning, which requires teachers to communicate to children the goals of their activities and the quality criteria to be applied so that children themselves can assess where they are in relation to the goals and, with their teacher, decide their next steps in learning. Teachers also provide feedback to children, not in the form of a judgment of how good their work is but of suggestions for how to improve it and to go further.

Although not all learning in science involves inquiry – there are some things, such as conventions, names and the basic skills of using equipment, that are more efficiently learned by direct instruction, as and when they are needed – it is important to ensure that inquiry is used where the aim is for real understanding that builds big ideas. On the other hand, teachers need to beware of pseudo-inquiry, where there is plenty of practical activity – observing, measuring and recording – but a lack of involvement of the children in making sense of phenomena or events in the natural world. This may be because the teacher is doing the interpretation for the children. It may also be that the content of the activities does not lead to the development of scientific models or explanations, a not uncommon occurrence at the primary level. Teachers who are unsure of their scientific understanding, tend to keep to rather trivial content, regarding science inquiry as a set of skills, rather than an opportunity to gather and interpret data and to reach conclusions based on available evidence (Harlen and Holroyd 1997).

In summary, interpreting inquiry-based teaching in this way means that teachers activities include:

- enabling children to reveal to themselves, their peers and the teacher, their pre-existing ideas and skills relevant to studying the phenomena or events involved in particular activities;
- probing children's ideas and skills by questioning, observing, and listening during the course of activities;
- communicating to children the purpose of their activities and how they can judge progress;
- ensuring children's access to a range of sources of information and ideas relating to their science activities;
- fostering written and oral expression in clear and correct language, while respecting free expression of children;
- providing feedback to children that reflects and communicates the criteria of good work, and helps them to see how to improve or move on;

- modelling scientific attitudes such as respect for evidence, openmindedness and care for living things and the environment;
- encouraging through appropriate questioning the use of inquiry skills in testing ideas;
- engaging children regularly in group and whole-class discussions where scientific ideas and ideas about science are shared and critically reviewed;
- using information about on-going progress to adjust the pace and challenge of activities;
- providing opportunities for children to reflect on their learning processes and outcome;
- identifying progress towards both short and longer-term goals of learning.

If we recall that pedagogy, in its broadest sense, means not only the act of teaching but also the theories, values and justifications that underpin it and the skills and creativity needed to provide effective learning activities and to engage children in them, then the size of the task of encouraging change becomes clear. This is the role of teacher education and continued professional development, to which we now turn.

TEACHER PROFESSIONAL DEVELOPMENT`

Implementing inquiry-based pedagogy in primary schools in depth and on a large scale certainly is a challenging and lengthy process. But the effort required is justified by the need to prepare the new generations for the 21st century. There are several facets to the implementation: institutional, financial, cultural. The central one, however, is the professional development of teachers (European Commission 2007, OECD 2008a). Taking into account the variety of recruiting levels, practices, salaries and social status of teachers, size of classes – all factors which vary widely from place to place among countries and even in a given country – nevertheless some essentially common principles and difficulties can be discerned, relating to teachers' image of science, the gradual development of expertise in teaching and the role that formative evaluation can play in implementing change.

Teachers and science

While literature, arts, history or even mathematics are often familiar to primary school teachers, either through their past studies in secondary school, reinforced by their vocational training or reading, their understanding of natural sciences may be limited to a collection of facts about the phenomena of nature. This leads them to a view of science teaching as simply ensuring that students know and memorize these facts. In addition, reflecting the way science has often been taught to them, discoveries and explanations are presented without their historical perspective to reflect the flavour of science as a human adventure.

Today, the media present the great achievements of modern science using images of complex instruments and abstract concepts (black holes, genetic transmission). This can easily convey the impression of science as something quite outside the phenomena experienced in daily life (a shadow, a cloud, boiling water) and that study of these phenomena – precisely the ones available in a primary classroom – no longer qualifies as science. In addition, breaking science into specialized sub-disciplines (physics, chemistry, biology…) does not help understanding of the deep unity of science as a *process* of developing knowledge, aiming at unveiling the truth, without ever fully reaching it.

It is essential that professional development aims at progressively modifying teacher's vision of science (Murphy *et al*. 2007). Professional scientists have a unique role there, and may greatly contribute to this change, telling stories, sharing their own practices, coaching teachers. As Lord Kelvin (1824-1907) said: *Blow a soap bubble and observe it for a whole life, you will discover the whole physics in it*. Using the environment, connecting science to other subjects of knowledge (especially history), making activities relevant to children's lives and, whenever appropriate, blending scientific knowledge with indigenous knowledge, are ways of breaking the vision of science as an ivory tower out of reach for anyone but specialists.

Teachers and inquiry in the classroom: from novice to expert

Prior to being an active pedagogy, inquiry is a mental attitude which has to be developed. Pilot projects of the implementation of inquiry-based science programmes in various countries show that it may well take five years of practice for a *novice* teacher to become first *competent*, then eventually *expert* in inquiry-based pedagogy (Bransford *et al.* 1999), assuming the help of professional development. Once expert, the teacher can contribute to the dissemination of inquiry practice among colleagues. This stage can only be reached with a full and active participation of the teachers in learning communities (Peer Learning Activity 2006, Sarmant *et al* 2010) involving:

- first-hand experience of inquiry in observing daily-life phenomena, making experiments, proposing hypotheses, writing conclusions in relation to investigations similar to those undertaken by children; then conducting them with children and reflecting on their own practices. In this process, contact with reality should be always preferred to ICT simulations;
- developing their own pedagogical resources, including material, events or phenomena for investigation;
- learning to accept awkward or unexpected questions from students, recognising some of these questions make deep sense, and knowing how to deal with them;
- understanding the subtleties of the science learning process in the primary school, where the role of the teacher is to be a guide for stimulating and satisfying curiosity rather than a reservoir of knowledge; being prepared to say *I do not know!*
- meeting required curriculum demands – usually mandatory and not necessarily built around inquiry – through lessons organised for inquiry-based learning.

This progressive acquisition of expertise requires great patience from the teachers: therefore it is not surprising that, in all pilot projects, coaching by scientists and teachers trainers has proven necessary for the process to continue and succeed. It is crucial to break down the isolation of the single teacher and tackle lack of confidence. This will be achieved through various means: collective work of teachers, interactive resources through Internet, community involvement (e.g. the EU funded *Pollen* project, Pollen 2009) and scientists' support. Experience shows that distance training with ICT tools, if efficient in terms of cost and coverage, cannot fully replace human contact organized at local or national levels.

Formative evaluation of teachers' practice

Inquiry-based pedagogy in science departs so deeply from traditional pedagogy that teachers need measurement tools to appreciate their own progress (James and Pedder 2006: 30). Tools can be developed to collect data by: observing teachers' classrooms practice in a systematic, comparative way; observing student's activities in detail; studying of students' notebooks and teachers' plans, analysing the science content of activities; noting how material is used in a classroom sequence, etc. These data enable the teachers and others to recognise progress in inquiry-based practice, identifying strong and weak points to inform further action (Saltiel and Duclaux 2010).

A WORLDWIDE MOVEMENT IN RENEWED SCIENCE EDUCATION`

Stressing the value of the principles involved in inquiry pedagogy for science education is certainly not a new story. In the Western culture, Socrates, Comenius, Michael Faraday, Maria Montessori, Henri Bergson, Célestin Freinet, Jean Perrin, Frank Oppenheimer and many others have for centuries and decades shown the value of an active, questioning pedagogy in place of learning facts by heart. What is really new within the last decade is, on one hand, a better scientific understanding of the process of cognitive learning as discussed earlier and, on the other hand, the global concern that school systems, especially the science education they provide, appear unsuitable for the challenges of the times, for developed countries as well as for emerging ones (Berthélémy 2007, OECD 2008c). There is a remarkable consensus concerning the value of an inquiry-based pedagogy, as we define it here in depth. It has inspired a great number of pilot projects across the world, irrespective of the state of the development of a country or the resources of its education system (OECD 2008a). Certainly, it is particularly noteworthy and interesting as a key to the future that the concern for science education is not limited to scientists but seems to be shared by politicians and economists.

What is striking is the unforeseen and decisive role that the scientific community is playing in proposing, implementing and supporting these projects. It is certainly not the simplicity of the scientific concepts taught in primary school which deserves such attention, nor is it only concern about the lack of interest of the younger generation in scientific careers in developed countries. Rather it is the clear perception of the part that a renewed science education has in the development in all people of 'the capacity to use science knowledge, to identify questions and to draw evidence-based conclusions in order to understand and make decisions about the natural world and changes made to it through human activity' (OECD 2003: 33). The role of the science community is manifest in the involvement of Science Academies across the world, organized within the InterAcademy Panel (Harlen and Allende 2006, 2009, Allende 2008, Alberts 2009, Léna 2009). First-hand practitioners of science are needed to make the fundamental change that is required in the image of scientific process among teachers. At the same time the magnitude of the change from traditional teaching methods cannot be achieved by the education institutions alone and greatly benefits from international cooperation, exchange of good practice and resources, and collaboration in research.

CONCLUSION

Two common themes stand out in this worldwide movement to reform science education: the response to evidence of the effectiveness of inquiry-based learning and teaching; and the importance of beginning science education in the early years of schooling and continuing it through primary education. Whilst there are undeniable reasons for making the changes required in these themes there are equally severe problems to overcome in doing so effectively. It is not a matter of creating new curricula, textbooks or materials for children to use. Important though good classroom materials are, real change is ultimately dependent on the teacher. Massive evidence and sound arguments relating to how learning takes place, supported by findings of neuroscience, create the case that children learn best when they are actively engaged in making sense of their experiences, when they are talking about and explaining their ideas and when, particularly in their early years, they have direct physical contact with the objects they are studying. In order to provide these conditions for learning, for many teachers, radical changes are required in their view of their role – from one as controller of learning and source of information, to one that acknowledges that children do the learning with the support of the teacher – as well as in their attitudes towards science and their personal understanding of science and of scientific activity.

Radical changes of these kinds require professional development of teachers on a large scale and a permanent basis, involving inputs from many different sources. The cost of this provision is not negligible but should be seen as an indispensible investment and one which can benefit from the existing contribution of the scientific community. Science education is crucial to our society and genuinely continuing professional development is central to the necessary renewal of science education.

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PART I

KNOWLEDGE AND SKILLS IN SCIENCE AND TECHNOLOGY PROFESSIONAL DEVELOPMENT

HANNO VAN KEULEN

2. INTRODUCTION TO PART I

Knowledge and skills in science and technology professional development

On Friday, March 11 2011, an earthquake with magnitude 9.0 and a devastating tsunami hit Japan. Undoubtedly, the next Monday, countless children all over the world will have asked their teachers about these events. “What is a tsunami?” “Where do earthquakes come from?” “How is it possible that so many buildings still stand after such an earthquake?” Probably, the next few days, children will have asked about nuclear energy and its risks and benefits. Everyday, children come to school poised with questions about the natural and material world they live in. “Why do leaves turn red in October?” “How does bubble gum work?” Some questions may be easy to answer and depend upon common sense knowledge, but in general, this will not be the case. Do you know exactly what happens in leaves that turn red (Hanson, 2007)? How do we expect teachers to react to all these questions? Or, rather, how do we prefer them to react? What knowledge do they need for adequate reactions and how would they acquire such knowledge?

It is hard to imagine a domain that is as knowledge intensive and expanding as science and technology. Pliny’s *Historia Naturalis*, which was compiled in the first century AD and can be considered to be one of the first attempts to map the area, describes some 20.000 facts. The *Encyclopaedia Britannica* from 1768 contains more than 100.000 articles, whereas nowadays Wikipedia has more than 2 million articles in the English language alone. Some areas of science produce over 40.000 academic articles each month (Börner, 2010). Everyday, new specimens are discovered in tropical forests. New sub-microscopic particles are created in cyclotrons. New materials result from research in nanotechnology. New galaxies are spotted in remote parts of the universe. And who knows what discoveries will be made when, for example, the successor of the Very Large Telescope will be in place at the European Southern Observatory at Cerro Armazones in Chile? This successor will either be the Extremely Large Telescope with a mirror of 42 meter in diameter or maybe even the Overwhelmingly Large Telescope, if engineers succeed in finding ways to construct and stabilise its proposed 100-meter diameter mirror.

The sense of humour with which these ambitious projects are baptized may be wasted on primary school teachers, however. ‘Overwhelmed’ indeed is an

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adequate description of their reaction to state of the art science and technology. For a large majority of teachers, their ambition is to work with children, not to be a scientist or engineer. Many of them even qualify for the stigma of being a 'non tech' (Motivation and Young Works, 2010). Their knowledge is reported to be shallow, as is their self-efficacy with respect to teaching science and technology (Murphy, 2007; Traianou, 2007). Yet, the preparation of the next generation of scientists, engineers and technicians, as is the general scientific and technological literacy of all citizens, is in their hands. And it is vital not to wait too long because children start to make career choices at an early age.

For children, an understanding of the material world already starts during infancy. Babies banging objects together develop the law-like concept that solid things cannot penetrate each other. Consequently, as toddlers, they know better than try to walk through a closed door (cf. Duschl, Schweinsgruber and Shouse, 2007; Siegal, 2008; Goswami, 2008; Wolfe, Kluender and Levi, 2009). During pre-school and kindergarten, children elaborate upon this intuitive, tacit knowledge and expand their understanding of such concepts as force, motion, equilibrium or change. Playing the seesaw can be the first step towards the lever rule; the experience of swinging helps to prepare for an understanding of pendulum motion. What children do with sand and water at the playground is not so radically different from the way geoscientists study delta formation in large estuaries or even on Mars (Kleinhans, Bierkens and Van der Perk, 2010). The rise and fall of a cake that wasn't properly battered intrigues children and food technologists alike (McGee, 2004). So many chances are waiting to be exploited by sharp and anticipating teachers!

But does this mean that secondary school and teacher training college will have to supply primary teachers with knowledge of the lever rule, Huygens' formula for determining pendulum motion, the basics of hydrodynamics, and differences in solubility of air bubbles in margarine versus butter? In it self, each piece of knowledge from the wonderful world of science and technology is worth to be known, but each fact is also in a way trivial and non-essential. There is simply too much to know to cramp it in your head pre-service.

To make things even more complicated, primary schools are preparing children for a future nobody is able to forecast with sufficient level of precision. Educators all over the world failed to anticipate the computer or the Internet. Which new technologies that will change our lives will emerge during the next decades? Will it be ways to extend and remake our bodies using biotechnology and robotics? Lightweight infrastructure using new materials and distributed intelligence? Embedded systems that can sense, understand and act upon their environment? Computer simulations of complex social problems that will assist citizens making better choices in their daily lives (IFTF, 2006; 2010)? It seems obvious that our planet faces serious sustainability problems. Dealing with our climate, improving energy efficiency, supplying water and food for all, and preparing for pandemics are a few of the challenges our children will have to take on (Van Santen, Khoe and Vermeer, 2010). We'd better prepare them at an early age, then.

In this part of the book, questions pertaining the knowledge and skills in science and technology professional development are elaborated from four different perspectives.

In chapter 3, Baartman and Gravemeijer focus on the key competencies of the future workforce in the context of social and technological changes. They make an effort to identify scientific and technological literacy for the 21st century and focus on the skills that will be in demand in the near future. They suggest to emphasize categorising, thinking in terms of variables, understanding cause-and-effect, means-end, and function-realisation relationships, visualising, schematising and modelling as core technological and scientific thinking skills.

In chapter 4, Rohaan and Van Keulen investigate the so-called Canon of the Sciences, an attempt (perhaps one in many) to pinpoint 'what everyone should know about the sciences'. The fifty items in the Canon qualify for the kind of cultural scientific literacy that enables children to participate in debate and decision-making. The chapter focuses on what primary school teachers and students and teachers in teacher training know of these topics.

In chapter 5, Van den Berg and Van Keulen investigate the possibilities for (mandatory) knowledge bases for science and technology teaching. They also point to the problem that, in order to combine the conflicting demands of being comprehensive and concise at the same time, there is a tendency to escape to lists of items that are conceptual rather than factual. Words like 'gravity' and 'sustainability' certainly indicate important areas of knowledge, but you cannot 'know' gravity like you can know Newton's formula for gravitation.

This part of the book closes with chapter 6, by Steenbeek, Van Geert and their co-authors. They shift the attention from teacher knowledge to teacher capacity to jump to the occasion: to recognise talents of children and interact productively. "Having eyes, giving eyes, receiving eyes". This may be the clue.

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LIESBETH BAARTMAN AND KOENO GRAVEMEIJER

3. SCIENCE AND TECHNOLOGY EDUCATION FOR THE FUTURE

INTRODUCTION

Our current society is deeply influenced and shaped by artefacts, ideas and values of science and technology, for example in health care, energy, transportation and communication. Also, issues such as pollution and nuclear energy become objects of public debate. In their jobs, professionals are confronted with an increased use of information and communication technologies and the need for flexibility and life-long learning. 'Non-science-jobs', such as nursing, increasingly require an understanding of science and technology. It is thus not only important to educate people in science and technology for science-related jobs, but for work in general (Rodrigues et al., 2007). Science and technology education should enable future citizens to live and work in this society with reasonable confidence and comfort (Forman & Steen, 1994; Osborne, 2007). In the Netherlands, a start is being made with innovating science and technology education in primary school with the Dutch VTB-Pro project that aims at promoting and improving science and technology education. A sustainable innovation has to anticipate the demands of the society in which the students will come to live in. Changes in the curricula of primary education and professional development of primary teachers are long-term endeavours. Therefore, this chapter looks at the content of science and technology education from the perspective of the needs of employees of the future.

Levy and Murnane (2005) present an economist perspective on current labour market developments, which is increasingly shaped by computers and globalization. For example, computers can substitute for human workers when tasks can be expressed in series of rules. This implies that routine cognitive and manual tasks are likely to be taken over by computers, leading to the loss of this type of jobs. On the other hand, computers can complement or help professionals in other types of jobs, in which computers for example visualize complex processes by means of graphs or models (Gravemeijer, 2009). This requires an understanding of science and technology, as using a model without understanding leaves one vulnerable to mistakes. Goos and Manning (2007) confirm the Levy and Murnane study. They studied labour market developments in the UK in the last decades, and found that jobs in upper wages and the lowest wages (i.e., non-routine cognitive and non-routine manual) indeed increase, whereas jobs in the middle

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