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Children and the Teaching and Learning of Science: A Historical Perspective

Edgar Jenkins, ***Centre for Studies in Science and Mathematics Education, University of Leeds, LS2 9JT, UK***

edgarjenkins@btinternet.com

Although schools have existed in some form or other for centuries, it was not until the nineteenth century that it became the norm for young children to receive an elementary education. Such education, provided by the state or organisations such as the churches, was initially not always either free or compulsory, and for only a small minority of pupils did it lead directly to any form of secondary education. In many countries, these limitations remain to this day.

The historic distinction between elementary and secondary schooling rested on assumptions about the roles that pupils from the two types of school would eventually play in society, i.e. upon social class. In many countries, but not all, those assumptions prevailed until after the Second World War, when changes in the structure of schooling allowed all pupils to pass from a primary school to receive some form of secondary education.

In what follows, the focus will be upon developments since the beginning of the twentieth century. Since that time, the rationale, form and content of the education of young children have been shaped by many factors. In some countries and at different times, as in Germany in the 1930s (Weiss 1994), China after 1949 (Jenkins 2004) or the former Soviet Union (Wrinch 1951), political ideology was paramount in governing the work of schools and of education more generally. In other cases, religion, sometimes allied to nationalistic, imperial, ethnic or linguistic concerns, has also been a powerful influence, often serving to promote a number of unique features or to limit or exclude some aspects of the elementary curriculum commonly found elsewhere.[1] These factors require more detailed attention than is possible in this short chapter. Equally it is not possible to do more than simply acknowledge here that any wide-ranging historical narrative would need to take account of the important differences that stem from concepts such as *Didaktic* and *Bildung* that have no direct counterpart in the Anglophone world. Instead, attention will be focused upon the ways in which ideas drawn from the history and philosophy of science and from psychology have shaped understanding of the rationale, content and pedagogy of elementary school science.

Despite some significant early initiatives (e.g. Layton 1973), securing a place for science in the elementary/primary school curriculum was to be a long struggle. In the closing decades of

[1] Such distortions of science have a long history. Layton (1973: 25-6) recounts a lesson on 'scriptural natural history' given in schools in England in the 1840s. Even today, some countries or states forbid the teaching of the theory of evolution or require that equal time be given to other accounts such as creationism or intelligent design. See also Nanda 2003, 2005 and Hongladarom 2000.

the nineteenth century, the British chemist Henry Edward Armstrong (1848-1937) was campaigning vigorously for the teaching of science to young children (Brock 1973). He based his campaign on what he called his heuristic method in which pupils were to be placed as far as possible in the position of an original discoverer. Sixty years later, his approach became known as teaching by investigation and was associated with the notion of learning by discovery. Today the fashionable term is that favoured by the European Union: - Inquiry-Based Science Education, or IBSE (EU 2007). In the United States, it was the writings of his contemporary, John Dewey (1859-1952), that were of greatest importance for much of the first half of the twentieth century, exerting a dominating influence on the teaching of practical science and on the education of teachers (Dewey 1910; Rudolph 2005).

Armstrong and Dewey could not have been more different as people or in their perception of what the science education of young children was for. Even so, they shared a belief in the fundamental importance of getting young people to learn how to tackle problems, in short, to think and not simply acquire knowledge. For Armstrong, this meant seeking to solve *scientific* problems by engaging in *scientific method*, something he regarded as little more than organised common sense and analogous to the way in which a detective solves a crime. For Dewey, it meant acquiring his so-called *model of thinking* and applying this in the context of the everyday lives of the learners. Although Armstrong's and Dewey's ideas were widely misunderstood and misapplied, their belief that science teaching is about inquiry, about enabling children to learn how to think and tackle problems for themselves, has remained fundamental to the rhetoric, if not always the practice, of science education to this day.

The early years of the twentieth century witnessed a growing rejection of the faculty psychology that had underpinned so much of nineteenth century schooling, along with a significant shift in our perception of childhood and therefore in our understanding of what it meant to teach and learn. That shift owed much to the ideas about child psychology and development represented by the naturalist disciples of Froebel, Pestalozzi and Herbart, all of whom were influential in continental Europe long before they had an impact in England (Jenkins 1979; Jenkins and Swinnerton 1998). The emphasis in early years education thus gradually came to be placed on developing the latent powers of the child, although there was little agreement how best to do this. In a characteristically vigorous response to the growing acceptance of these ideas, Armstrong railed[2] against psychology in general and complained that in future the teaching of science to children would be governed simply by what children were interested in, to the neglect of other, notably disciplinary, considerations.

The consequences of this shift in understanding of teaching and learning were not confined to pedagogy: there were also consequences for the content and structure of the curriculum. In many countries, the school curriculum had been structured by introducing topics in what was perceived as the increasing order of conceptual difficulty for children to learn. So, for example, elementary ideas about heat would be taught before pupils were introduced to concepts drawn from electricity or chemistry (Jenkins *op.cit.* 1979). Now the task became

[2] Writing in 1924, Armstrong expressed his disillusionment at the way in which school science was developing in England, writing that 'No one believe in "doing" more than I do – but the 'damned boy' needs drilling. We forget this and ever twaddle of playing on his interests' (Armstrong, quoted in Brock 1973: 145).

that of drawing upon what was known about the cognitive development of young children to determine the order in which scientific ideas could be presented in order to optimise learning.

It was a task approached in different ways by, for example, Charlotte Bühler, Percy Nunn and Alfred North Whitehead. Whereas Bühler in Germany drew upon her empirical work as a developmental psychologist (Bühler 1922), Nunn (1907,1920) and Whitehead (1922) in England turned to the history of science to assert a parallel between the way in which scientists were assumed to work and the way in which children's interests were thought to develop with age. Scientists were said to be motivated first by a sense of curiosity and wonder, then by a desire to understand and use the forces of nature and, finally, by the need to establish the fundamental principles governing the natural world. Children, it was claimed, were motivated by these same three motives, of wonder, utility and systematisation, each of which was dominant at a particular age, with wonder and curiosity associated with young children. The task for teachers therefore was to match curriculum and pedagogy to the appropriate 'motive' of those being taught.

The history of science, developing rapidly as an academic discipline in the early years of the twentieth century, also came to be seen as offering other illuminating insights into the nature of scientific inquiry. In addition, the incorporation of aspects of the history of science into the elementary school curriculum had the further advantage of lending itself readily to the storytelling of heroic achievements, sometimes overtly coloured by patriotic or narrower political considerations[3].

Yet, despite several promising initiatives, over half a century was to elapse before elementary schooling began to reflect anything other than a narrow view of what the sciences could offer to the education of young children. In the meantime, the focus in most countries remained firmly on the locality and the environment. In Germany, for example, the *Heimatkunde* of the *Grundschule* sought to help children acquire knowledge and appreciation of the world around them through observing natural objects and phenomena throughout the seasons, to promote an inquiring attitude, and to lay the foundations of later, more specialised, work. *Heimatkunde* was a notable influence on the ideas of the developmental psychologist, G. Stanley Hall, in the United States.[4]

Although there is no direct parallel in other education systems, *Heimatkunde* had much in common with the programmes of Nature Study developed elsewhere, including the UK (Bailey 1903) and the USA (Champagne & Klopfer 1979, 1980). Unfortunately, many programmes of Nature Study were neither nature nor study (Jenkins, 1981) although in the hands of a skilful and knowledgeable teacher Nature Study could succeed in fostering

[3] It is interesting to compare school science textbooks used in different countries. While the achievements of internationally renowned scientists such as Newton, Einstein or Haber are always acknowledged, significant differences emerge in the presentation of lesser known national figures.

[4] See, for example, Koelsch (2002) for Hall's ideas on teaching geography. Hall spent some time in Germany where he came across the notion of *Heimatkunde* and was inspired by the psychological ideas of Wilhelm Wundt Hall and by Ernst Haeckel's recapitulation theory of embryonic development. Darwinian evolutionary theory was also important in his thinking. He became the first American to earn a doctorate in psychology and the first President of the American Psychological Association.

children's curiosity, increasing their self-confidence, developing a number of basic scientific concepts, and promoting their language and social skills.

Despite its substantial shortcomings, Nature Study has bequeathed a wide-ranging legacy, not least the belief that it is educationally and perhaps morally beneficial for young children to explore the natural world around them in an active and inquisitive way. It has also served to underline the idea that teaching science to young children should be concerned more with the acquisition of these personal attributes than with the learning of a body of scientific knowledge and it emphasised that, as far as possible, the teaching should be related to children's everyday environment and experiences. Finally, it has helped to consolidate the view that young children should be taught science without the overt distinction between the basic disciplines that characterises science education at the secondary level.

It was the First World War which served as a major catalyst in promoting those ideas about the education of young children that have come to be known as 'progressive' or what the Australian historian Selleck has called 'the new education' (Selleck 1972), although some countries were already well ahead of others. In the immediate post-war years, the ideas of Rousseau, Pestalozzi, Froebel, Whitehead, Dewey, Montessori, Nunn, Russell and Rachel Macmillan, to name but a few, were revisited and recast for a post-war world that demanded something different from that offered by the pre-war education systems that were deemed to have failed so many. Inevitably, it took time for this progressive approach to the education of young children to find widespread acceptance, so that change in the inter-war years was very gradual and uneven both within and between countries.

This 'progressive' approach both required and prompted a greater understanding of how young children learn and could best be taught. Gesell studied children through a one-way glass and began to develop his ideas about maturation (Gesell and Gesell 1949), Charlotte Bühler continued to explore how far pedagogical goals could be co-ordinated with child development,(Bühler 1949) and Jean Piaget developed his stage theory by interviewing individual children (Piaget 1929). Some countries saw the establishment of new and experimental types of school. The pioneering work of Susan and Nathan Isaacs in England (Isaacs 1930), based upon their experimental Malting House School, is an important and seminal example. Here, the Isaacs studied children interacting within an environment specifically designed to stimulate their powers of inquiry and imagination. Like Piaget, they regarded children as active learners but they rejected what they regarded as the rigidity of his account of conceptual development, arguing, for example, that even children as young as seven years old were capable of formal reasoning. For a variety of reasons, the Isaacs' work was much better known and more influential in England and in many other countries than that of Piaget until well after the Second World War. This is partly because Piaget's writings were in French but it also owed something to the fact that his findings derived from clinical interviews conducted with individual children, an approach that contrasted strongly with that adopted by the Isaacs at the Malting House School[5].

That war transformed the position of science in society and led to a greatly increased demand for qualified scientific and technological personnel. With the added spur of the subsequent Cold War, the need to meet this demand and to reform school science education became a political imperative in many countries. Curriculum initiatives in the USA in the 1950s were soon followed by a global movement for reform as countries rushed to modernise the content, pedagogy and assessment of school science[6]. If the initial focus on secondary education is understandable, primary school science faced several unique challenges that were to hinder its development and rapid implementation. The rationale for teaching science to young children was sometimes contested, few primary school teachers could call upon a scientific background and there was little in the way of experience to determine what and how science should and could be taught at the primary level.

Inevitably, different philosophical and psychological perspectives led to different approaches to the scientific education of young children. In the USA, the ideas of Gagné (Gagné 1970) were used to underpin a course entitled *Science: - A Process Approach*[7]. The English equivalent was entitled *Warwick Process Science* (Screen 1986) and parallel initiatives took place in a number of other countries. Gagné claimed that scientists secured knowledge through the operation of processes such as observing, classifying, describing, communicating, drawing conclusions, formulating hypotheses, controlling variables, experimenting and so on. He argued that these processes could be taught to, and learnt by, all students, including young children, and the curriculum project, *Science: - A Process Approach,* was directed to this end. However, there are several criticisms that can be, and were, levelled at Gagné's approach to teaching science of which the most obvious and damaging is that his account of how science works was not supported by philosophers, historians or sociologists of science. Even so, his approach to scientific education belongs firmly in the tradition that science should be taught in a way that reflects a view about science itself as a form of inquiry.

What might be termed an Anglo-American emphasis on processes in primary science was not confined to these countries. It permeated the African continent where it was highly influential in the *African Primary Science Programme* (APSP) which was adapted, or adopted, in many African countries. Perhaps predictably, such an approach did not sit comfortably alongside more traditional approaches to teaching in these countries which traditionally relied heavily on observation and imitation rather than inquiry.

Although the process approach to science education was heavily criticised (Millar and Driver 1987), its underpinning philosophy was soon transformed to support a curriculum based on the acquisition of allegedly discrete skills or competences. However, the psychology

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[5] The School, near Cambridge, operated from 1924 to 1929. Its prospectus stated that the method of teaching employed with children from 3 to 7 years of age involved eliminating 'the authority of the pedagogue' and replacing it by 'the attitude of the co-investigator ("Let's Find Out")'.

[6] In 1972, Lockard recorded over 800 curriculum projects in science and mathematics across the world.

[7] The project lasted from 1960 to 1974 and produced a range of kits, teaching materials and classroom exercises.

underpinning the skills-cum-competences approach to science education soon proved equally open to criticism. Observing, classifying and hypothesising are things that everyone, including young children, does all the time. In addition children, like adults, do not observe in some unbiased, detached way: what they see depends upon what they are looking for. Observing is not a simple process or skill but a subtle, neurologically complex activity that involves checking what we 'see' with what we think we 'see' and this depends crucially on the way in which we perceive the world.

Further dangers associated with conceptualising the nature of science in terms that are readily and beguilingly transformed into educational objectives soon re-emerged. It is obvious that young children are curious and that they explore, and try to make sense of, the world around them through play and language. This, however, does not sustain the claim that children engaged in such exploration are being scientific or that children are 'natural' scientists. Many educators have argued that 'Learning science and doing science proceed in the same way' (Harlen 1996: 5) or that 'The schoolboy learning physics is a physicist' (Bruner 1960: 14). Claims of his kind were widely used to justify many of the activities presented to young children as part of their scientific education and, occasionally, to suggest that what mattered was engagement in those activities rather than learning outcomes. For example, children were sometimes asked to explore which of several different paper kitchen towels is the most efficient at absorbing water. This can be an engaging and entirely worthwhile activity in which children work out how to undertake the task, begin to understand the need to control variables, and develop their writing and social skills. The *scientific* question, however, was rarely, if ever, addressed, perhaps because it is too difficult for young children to begin to answer. This is *why* the paper of one kitchen roll is more or less absorbent than another. It is this deeper theoretical understanding that illuminates the nature of absorbency and which, if necessary, could be brought to bear on a much wider range of problems than that prompted by simply measuring the effectiveness with which different paper towels absorb water.

Another danger in asserting that an imaginative and creative activity such as science can be reduced to a set of processes or skills stemmed from the frequently made assumption that this approach has a universal applicability. Reflection, as well as experience, suggests that this is not so. As an example, a scientific hypothesis has qualities that distinguish it from other kinds of hypothesis, not least that it must be testable.

The process and skills-cum-competences approaches to science education were by no means the only ones to achieve prominence in the 1960s and beyond. The neo-behaviourist, David Ausubel, for example, argued that the most important factor determining new learning was what was already known and he developed the idea of advanced organisers to bridge the gap (Ausubel 1963).

In contrast, many primary school initiatives, including the *Junior Science Project* and the *Science 5-13* project in the United Kingdom, drew less directly upon ideas about the nature of science than on Piagetian stage theory in constructing science curricula for young children. The *Junior Science Project* was essentially about encouraging and helping teachers to provide suitable materials and situations within which children could ask questions and engage in reasoned activity. Its successor, *Science 5-13*, sought to move beyond this towards a programme of primary science activities that could be structured and sequenced by teachers in accordance with Piagetian principles (Jenkins and Swinnerton *op.cit.*). This project also drew upon behaviourist ideas and the Tyler-Bloom model of curriculum development by specifying objectives. This emphasis on research into children's cognitive development as a basis for constructing a science curriculum was evident in the USA when Robert Karplus drew upon Piagetian ideas in his *Science Curriculum Improvement Study*. In collaboration with Herbert Thier, this initiative grew into a 15 year project that developed science teaching programmes from Kindergarten to Grade 6 (Karplus & Their 1967). Also in the USA, Jerome Bruner (*op.cit.*) presented his three stage constructivist model of representation (enactive, iconic and symbolic) to underpin his account of the process of education.

In the case of science education, this Piagetian emphasis reflected two things: first, a lack of an *experiential* base that might have derived from an established tradition of teaching scientific ideas to young children and, secondly, a beguiling confidence that empirical research, conducted in settings far removed from the primary classroom, could be applied in a relatively unproblematic way to curriculum construction and pedagogy. Subsequent experience was soon to show that both of these aspects of primary science curriculum reform presented severe problems.

Addressing these problems prompted yet more curriculum initiatives with a stronger research-oriented, rather than developmental, focus. A *Match and Mismatch* project tried to identify and match activities to children's stages of cognitive development, and a *Science Processes and Concepts Exploration* project explored the ideas that primary school children held about basic scientific concepts and processes. The work quickly confirmed that even quite young children already had their own explanations for a variety of everyday observations and phenomena and that these were often very resistant to change. It also became clear that these same young children often had powers of reasoning and logical thought beyond those to be expected on the basis of Piagetian stage theory. It thus became important to identify and characterise children's explanations of everyday observations and phenomena, to examine how these came to be established and how, if necessary, they might be changed. Addressing these issues has characterised much of the research in science education of young children during the past thirty or so years.

The research literature relating to what have become known as children's misconceptions or alternative conceptions is now very large[8] and it has shown that many of the ideas that children hold about natural phenomena have a universal character. These ideas may stem from their own observations, from religious or mythical teaching, from conversations with others, from bad or inadequate teaching and/or from the interplay of all these factors. Reading this literature also reveals that understanding what children actually mean is not always straightforward. For example, although most children by the age of six or seven will say that

[8] The bibliography (Students' and Teachers' Conceptions and Science Education) complied by Reinders Duit and published on-line in 2009 by the Leibnitz Institute for Science and Mathematics Education (IPN) has approximately 8,400 entries in English and German.

the earth is round, they may also say it is flat, like a plate. So here there are two conceptions, only one of which can be regarded as approaching the correct notion of the earth as an oblate spheroid. This ability to hold simultaneously more than one concept to explain or categorise a phenomenon is common. Thus, while children aged 4 or 5 can readily give examples of solids or liquids, some will also define a liquid as something you can drink. They may also use their sense of taste to say that water is a liquid because you can drink it but vinegar is not because it doesn't taste good. The same children may well use their sense of touch to distinguish a solid from a liquid but also think that solids are always heavy and can't be bent. As any teacher of science to young children now knows, what they see is a powerful determinant of the explanations they offer, explanations that often lead them to over-generalise from a necessarily limited range of experience. For example, a magnet that slides down the door of a refrigerator because it is too heavy is judged *not* to be a magnet because it doesn't stick. Likewise, a magnet that sticks to one metal but not to another is judged to be a magnet only some of the time.

The question for teachers therefore became how best to provide young children with the range of experience and activities that would encourage the desired conceptual change. Regrettably, while the research literature relating to conceptual change is voluminous, there is a lack of agreement about how best to bring such change about. For some, it was, and remains, a matter of exposing children to situations that prompt cognitive conflict. For others, it is a matter of helping children to choose an explanation that is adequate for the purpose in hand whether or not it could be strictly described as scientifically correct. This, we should note, is exactly what adults frequently do. Well-educated adults talk about shutting a window to keep out the cold when in scientific terms there is no such thing as cold: it is simply an absence of heat. Likewise, adults all say that 'The sun rises in the east' when the sun does no such thing. Perhaps all that a historian can do is to note that everyone is capable of holding conflicting ideas about the natural world, that people usually manage to do so without difficulty and that they are adept at choosing an explanation that they judge adequate, not always correctly, for the purpose in hand. There are important implications here for science educators, science education and public engagement with science.

In the past half-century or so, the debate about how best to teach science to children, and not just young children, has been framed in terms of so-called constructivism, a term that has been applied to numerous fields of human activity from religion to literature and has come to mean whatever you want it mean. The temper of that debate within education is captured by two quotations.

> The constructivist view of teaching and learning has proved to be a powerful model for describing how conceptual change in learners might be promoted (Keogh and Naylor 1997, p.12)
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> [Constructivism is a candidate for] *the* most dangerous contemporary intellectual tendency…[because] it attacks the immune system that saves us from silliness (Devitt 1991, p. ix)

It is not appropriate here to trace the many varieties of pedagogical and philosophical constructivism that have emerged or to comment on the fierce controversies associated with them. What is clear is that the influence of constructivist ideas on school science education has been significant (Matthews 1998). However, it is important to remember that much of the on-going debate about constructivism has been conducted among the academic and research communities and the evidence suggests that in many education systems, constructivist ideas have still had relatively little effect on the classroom practice of many teachers.

As far as schools are concerned, the historical reality is that despite the enormous and unparalleled investment in science curriculum reform in the 1960s and 1970s, it was soon judged in many countries to have been much less successful in effecting change than had been anticipated both at primary and secondary level, although there were some local or regional successes and much had also been learnt about what could be done to teach science to young children. Many elementary school teachers made little or no use of the materials produced by innovative curriculum projects. Black, writing in 1983 of the *Science 5-13* and the *Junior Science* projects in the UK, claimed that they had 'fallen at the first hurdle – that of convincing teachers to take them seriously' (Black 1983: 30). The problem was not confined to the UK: as late as 1995, a TIMSS study of the education of 9 year olds found that in many of the countries surveyed, science received little or no attention in the primary curriculum.

How might this lack of commitment to primary science be explained? The favoured explanation is that teachers of young children lacked the necessary knowledge and/or confidence to teach science: in 2012, 39% of a national sample of elementary school teachers in the USA said that they didn't feel well prepared to teach elementary science. This explanation therefore probably has some wider validity, although there is also the issue of the availability of curriculum time and resources to teach practical science. There also lingered in some quarters a suspicion that science is too difficult to teach to young children, a concern that, from today's perspective, appears extraordinary. One key factor, however, would seem to be the degree of political control exerted over the primary curriculum. England can stand as an example of an education system which, since 1944, allowed primary schools a wide degree of freedom to organise their programmes of work. For the next forty four years, the result was that despite many pious statements and expensive projects, science failed to secure a place in the primary curriculum. In 1988, legislation changed all that with the introduction of a statutory national curriculum. Within a few years, all primary schools in England were teaching a broad and balanced science course and, supported by professional development and the science teachers' professional organisation, were largely doing so successfully. In those countries where greater political control of the primary curriculum already existed, the question becomes why was change here also so slow and uneven? In addition to the issues of teacher competence and resources, the answer in at least some cases may be that, in contrast to the secondary level, primary schooling initially lacked the support of powerful and influential professional scientific organisations able to articulate and willing to promote the case for teaching science to young children.

The distinction drawn above between different forms of political control of school curricula is, of course over-simple. A number of countries, including Germany, Australia and the USA, have a federal structure in which education is decentralised. In these circumstances, the relationships of local, state and federal initiatives in science education policy are diverse and complex, so that development of science education for children can be not only uneven but diverse. Thus while the USA has produced a series of national standards for science education, the translation of those standards into practical action remains for the most part the responsibility of the states and school boards. Australia offers a particularly and contrasting interesting example with the development of a national curriculum which includes science from the ages of 5 to 15.

Despite the difficulties of implementing primary science, when future historians come to look back at the history of teaching science in primary or elementary schools, they will undoubtedly see the last two decades or so as a time of enormous progress. A study, carried out in 2006 on behalf of the European Commission, showed that science formed part of the curriculum of primary education in all the countries surveyed (EU 2006). Sometimes taught as a discrete but integrated subject, the science was commonly specified in terms of topics or, less often, as objectives or learning outcomes. In other education systems, science found accommodation within broader programmes such as environmental studies. In addition, in all but three of these countries surveyed, the curriculum made reference to science in context, either in terms of the history of science or contemporary social issues or both. As in the countries of Europe, the teaching of science to young children elsewhere has become almost universally accepted as a component of the primary curriculum, although, as indicated above, its form, content and extent vary.

The reasons for this rapid transformation in the status of primary science are not hard to identify. During the last half century or so, the influence of scientific and technological developments on all aspects of everyday life has greatly increased. One major educational response to this greatly increased influence was the so-called Science-Technology-Society (STS) movement which produced curriculum materials and programmes designed to help students engage in informed debate about a range of socio-scientific issues (Solomon and Aikenhead 1994). Another was a rapid growth in interactive science centres and museums in major cities across the world, often with substantial outreach programmes designed for children. Such centres and museums can now be found in many cities and towns across the world and they form part of a global industry dedicated to communicating science to the wider public.[9] Such rapid growth was, in part, a reflection of the realisation at governmental level that without a greater public understanding of science, greater scientific literacy, science-related policies relating, for example to health or new technologies, would be more difficult to implement successfully[10]. There was, in addition, an acknowledgement by

[9] Note, for example, the work of the European Science Events Association (EUSCEA), the European Science Communication Network (ESCONET), the Association of Science-Technology Centres (ASTC), and the European Collaborative for Science, Industry and Technology exhibitions (ECSITE).

[10] The term scientific literacy has a long history and the notion itself has been much contested and criticised (see , for example, Shamos 1995). Along with 'public understanding of science', the preferred term is now 'public engagement with science'.

governments that meeting the demands of a rapidly changing and globalising economy placed a premium on scientific and technological skills. The political mood in the last two decades in most countries is captured in the opening statement of a report by the US National Commission on Excellence in Education in 1983. It boldly proclaimed that 'Our Nation is at Risk' because it judged that America was not well placed to face the scientific and technological challenges presented by its industrial and commercial competitors (NCE 1983). In the following years, similar messages appeared in reports from countries across the world. In 2004, a European Union report proclaimed that Europe 'needs more scientists' at a time when a succession of research studies showed that too few young people in the developed world, especially girls, wanted to pursue a scientific or technological career (EU 2004). As though all this were not enough to prompt a number of policy initiatives, the results of surveys such as TIMSS and PISA ensured that science education was promoted to the top of the political agenda and that this science education needed to be for all and not for just the few[11].

The consequent reports and recommendations for curricular and pedagogical reform would fill a large library but all recognised that the time had come to accord science a secure place in the education of young children, not least because of the belief that 'earlier is better' in gaining young people's interest. In some countries, this required revision of existing national curricula: in others, like England, a statutory national curriculum was introduced for the first time in nearly a hundred years. The teaching approach sought to actively engage children in their learning and, in the case of science, to undertake investigations of a practical nature, making use where appropriate of information and communication technologies. In most countries, an approach of this kind represents a reform that many teachers found challenging, although there are now many initiatives, some funded by the European Commission, designed to help them such as La Main à la Pâte in France,[12] the SINUS-Transfer initiative in Germany[13] and the POLLEN project[14].

The notion of engaging children in practical investigations, the so-called IBSE referred to earlier, is, of course, not new: it is only necessary to recall Armstrong, Dewey, Bruner and a host of others. Today, however, there is less readiness to offer overt and simplistic pedagogical prescriptions of 'how science works'. Instead, using concepts drawn from developmental psychology, philosophy, the language sciences and the history, philosophy and sociology of science, research attention is shifting towards promoting argumentation, that is, towards helping children to evaluate knowledge claims in the light of available evidence (Erduran & Jiménez-Aleixandre (2012). The production of teaching and learning sequences in argumentation has been a key objective of two EU-funded projects: Mind the Gap and S-TEAM. Most of these argumentation studies have been directed at secondary school students but there are important exceptions such as the RODA project (ReasOning, Debate,

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[11] There is a substantial research literature that is critical, on methodological and/or statistical grounds, of TIMSS and PISA. See, for example, Goldstein, 2004; Sjøberg 2012.

[12] www.fondation-lamap.org/

[13] www.sinus-transfer.eu

[14] The scientix website (www.scientix.eu) is a useful source of information about science education projects in Europe.

Argumentation) in Spain which included a three year longitudinal study with primary age pupils (Jiménez-Aleixandre *et al.* 2000). This importance on language reflects the more recent influence of Vygotsky[15], whose constructivist ideas differ from those Piaget in giving greater emphasis to the role of socio-cultural and linguistic factors in cognitive development.

The previous paragraphs have done no more that indicate the many different factors that have shaped the status, form, content and teaching of science to young children. However, despite the inevitable consequent shortcomings, two conclusions stand out: more science is now being taught to more pupils than at any time in history and their performance is now being judged not only nationally but internationally.

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Edgar Jenkins is Emeritus Professor of Science Education Policy at the University of Leeds, U.K., where he was Head of the School of Education and Director of the Centre for Studies in Science and Mathematics Education. His research has been concerned with the educational functions of science and the social and political history of school science education. He is the author of numerous books and articles and has recently (2013) co-edited a history of the science teachers professional organisation, the Association for Science Education.