International Handbook of Science Education

Part One A

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Although constructivism has the ascendancy among learning theories in the 1990s, this has not always been the situation. In the first half of this century, behaviourism was the dominant learning theory in education, at least in the USA (Schunk 1991). Published research in the USA prior to the late 1950s had a predominantly behaviourist tone, although cognitively-based research did occur without becoming mainstream (see the review by Oakes 1947). How these changes from behaviourist to cognitive theories of learning influenced the science education community can be discerned from observations of the research literature on learning in science education during this period.

In this chapter, we present a brief outline of the developments towards a view of learning that includes issues of mainstream constructivism of the late 1980s and the early 1990s, and issues of social constructivism that have gained increasing attention in science education. With regards to the different views of learning, we believe that rival positions emphasise different aspects of the learning process. Further research should not focus on the differences but present an inclusive view of learning and conceptualise the different positions as complementary features that allow researchers to address the complex process of learning more adequately than from a single position.

Initially, this chapter provides an overview of the various developments in views of learning in science education from behaviourism to constructivism, and describes frameworks for categorising current research on science learning. Secondly, we examine the role of Piagetian ideas of learning in science education, which leads to the third section which addresses conceptual change approaches from the perspectives of learning pathways, conceptual change theory and resistances to change. The fourth section of the chapter focuses on social-constructivist aspects of learning. The final section provides an overview of this chapter and a brief description of the other seven chapters in this section of the *Handbook*.

Chapter Consultant: Stella Vosniadou (University of Athens, Greece)

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From Behaviourist to Constructivist Views of Learning in Science Education

Scientists in the USA in the late 1950s grew increasingly concerned about the poor quality of science education in secondary schools and this concern led directly to the now famous curriculum development projects of the 1960s. This activity and the deliberations of concerned scientists and educators led to the book, *The Process of Education* (Bruner 1960), which 'served as both a reservoir and watershed' (Shulman & Tamir 1973, p. 1098) in changing and shaping the immediate future of science education. The four themes of Bruner's book each focused attention on learning and the learner. The first theme was concerned with the role of the structure of the subject matter in learning, emphasising that learning and teaching of structure is more productive than mastery of facts and techniques. The second theme was readiness for learning, especially how learning of new ideas involves revisiting them in the curriculum so that the learner can use them effectively in progressively more complex forms. The third theme involved intuition and analytical thinking that led to the notions of discovery and inquiry which were so influential for a long time. The fourth theme related to the desire to learn and how it might be stimulated.

These themes greatly influenced activities in science education as was evident in Shulman and Tamir's (1973) review in the *Second Handbook of Research on Teaching*, which identified the central themes in science education during the period 1963–1973 as being the structure of the subject matter of science education and the impact of major curriculum developments. In White and Tisher's (1986) chapter in the *Third Handbook of Research on Teaching*, these same two themes – the learner's acquisition of knowledge and the implementation of curricula – were used as organising themes in their review of research on natural sciences education.

The influence of different learning theories is evident in changes of focus in research in science education. In the decades before Shulman and Tamir's (1973) review, researchers were interested primarily in discovering whether or not changes in a teaching procedure or in a curriculum led to changes in students' performances. Attention to why or how these changes came about was of little interest and was less common. In his seminal paper comparing a quantitative study of student learning (and other output measures) among 72 Harvard Project Physics classes with a qualitative study of science classes in nine schools, Welch (1983) identified how the goal of the research and nature of the research questions changed the essence of the whole research enterprise. These changes towards qualitative studies, similar to those reported by White and Tisher (1986), involved researchers looking for reasons for any effects in learning and examining the details of learning outcomes.

By the late 1960s, the influence of behaviourist theories of learning in science education was waning and Piaget's ideas of intellectual development came into prominence. Even so, the focus of Piaget's research on the development of cognitive structures or cognitive operations by the individual was incorporated initially into research that was still influenced by behaviourism. This research examined Piaget's constructs of concrete and formal thinking and attempted to create conditions and design convenient measuring systems so that students could move from concrete to formal thinking in optimal ways. The major challenge to the focus of Piaget's research into learning in the 1970s came from Novak (1978) and his interpretation of the work of Ausubel (1968). Novak challenged whether children develop general cognitive structures or cognitive operations to make sense out of experience and instead asked whether they acquire a hierarchically-organised framework of specific concepts to allow them to make sense of the experience. Essentially, Novak argued that Ausubel's theory of meaningful reception learning, being dependent on the framework of specific concepts and integration between these concepts, provided a better analysis and explanation of the data from studies than did Piagetian stages.

Although research on students' learning in science from a cognitive perspective was evident in the first half of the 20th century, this interest in students' learning in science became a central aspect of research around the world only in the middle of the 1970s. There appear to be two major reasons for this research development (White 1987). First, the curricula designed in the 1960s and early 1970s had been far less successful in terms of improvements in the standards of science education, particularly in learning outcomes, than was expected from the effort invested in them. Second, various disciplines relevant to science education, such as philosophy of science, cognitive psychology and pedagogy, encompassed the notions of 'constructivism'. Initially, research in the middle of the 1970s focused on investigating students' learning of science phenomena, principles and concepts such as heat, energy, photosynthesis or genetics. The large number of empirical studies provide ample evidence that students' learning in many fields in the science curriculum is substantially different from the scientific concepts held by scientists. Most of these conceptions are held strongly and hence are resistant to change. As a result, research shows that students learn science concepts and principles only to a limited degree, sometimes persisting almost totally with their preinstructional conceptions, sometimes trying to hold onto two inconsistent approaches – one intuitive and one formal – and sometimes possessing genuine alternative conceptions which are unrecognised and undervalued in their potential implications. In research since the middle of the 1970s, science educators treated students' conceptions in isolation, topic by topic. When this led to limited success in modifying students' beliefs, researchers extended the scope of their investigations (Duit 1994).

Learning science is related to students' and teachers' conceptions of science content, the nature of science conceptions, the aims of science instruction, the purpose of particular teaching events, and the nature of the learning process. For example, many students hold limited empiricist views of the nature of science (cf Désaultels & Larochelle's chapter in this *Handbook*). Further, many students' views of learning and the learning process are limited in that they conceptualise learning as the transfer of prefabricated knowledge that then is stored in memory. Accordingly, science is primarily learned as an accumulation of facts. (See Sutton's chapter in this *Handbook* for a discussion of how scientific writing reinforces this way of learning.) This passive view of learning influences the students' conceptions of what counts as work in school. Classroom discussions of alternative viewpoints and negotiated consensus are not considered a part of the 'work' of the classroom, and simply are viewed as wasted time that hinders efficient progress (Baird & Mitchell 1986). The social aspects of understanding and learning are increasingly important (Solomon 1987; Taylor 1993) because knowledge construction requires an active process of interpretation within a social and cultural setting by a learner (see Roth 1995 and Metz's chapter in this *Handbook*). In this respect also, models and modelling play an important role in contributing to learning in classrooms and in other contexts (see Gilbert & Boulter's chapter in this *Handbook*).

Frameworks for Categorising Research on Science Learning

The different positions or orientations of learning taken by theorists have important implications for instruction. However, a major problem is the need to place the different positions within a framework so that commonalities and differences can be identified. Eylon and Linn (1988) made such an analysis by choosing four research perspectives referred to as *concept learning*, *developmental*, *differential* and *problem-solving perspectives*. Concept learning studies are concerned with the qualitative differences among the conceptions that students use to explain scientific phenomena and examine students' topic-related understanding of scientific concepts. Reviews of such studies include Driver, Squires, Rushworth and Wood-Robinson (1994) and Pfundt and Duit (1994). The developmental perspective offers a more global view of the learner than the concept-learning perspective and examines how individual conceptions change over time, often from a Piagetian or neo-Piagetian perspective to a Vygotskian perspective. In the developmental perspective, a major research focus is on what develops (see Metz's chapter in this *Handbook*).

The differential perspective examines individual differences in abilities and aptitudes and the interaction of these differences with instruction. Of specific interest are scientific proficiency, intellectual skills, psychological aptitudes relevant to scientific proficiency, and distributions of these skills across demographic groups. Studies of this type are no longer so common because the complexity of the interactions vary with other factors such as science knowledge, learning context and social context. The problem-solving perspective comprises studies of the processes or procedures that individuals employ to answer scientific questions. Of particular interest in this perspective is the research on characteristics of novices and expert problem solvers (Reif & Allen 1992) which shows that teaching general problem-solving skills is difficult because science topic-specific concepts influence reasoning and interact with general ability.

Farnham-Diggory (1994) acknowledged the problem of categorising in education, including categorising approaches to learning. She limited learning theories to three mutually-exclusive models which she calls *behaviour*, *development* or *apprenticeship* models. For her, the essential criterion for distinguishing the behaviour model of learning is a comparison of expert and novice differences on the same scale(s), with any difference observed being transformed by incrementation. Novices are systematically able to accrue her science knowledge types – declarative, procedural, conceptual, analogical and logical – until they reach expert levels. This category denotes learning as training in a particular behaviour. The existing cognitive structure changes only in that something new is added. This categorisation of learning looks essentially like that sought and examined from the large curriculum projects of the 1960s. In the development model, novices and experts are distinguished on the bases of their personal theories and explanations of events and experiences. Personal theories and the concepts and principles to be learned usually are embedded in different qualitative frameworks. Teachers challenge students' personal theories by questioning, contradicting and challenging that theory, in a process which she calls perturbation, so that the student is encouraged to revise it. The result is a qualitative shift in thinking and a reconstruction of her five types of knowledge. This categorisation of learning looks essentially like that introduced from the work of Piaget and the recent constructivist positions and is so broad that it encompasses all four of the learning perspectives described by Eylon and Linn (1988). In the apprenticeship model, the novice learner gets to be an expert through the mechanism of acculturation into the world of the expert. Often this learning of new knowledge is tacit and a novice's learning is facilitated by becoming a member of the culture of the expert.

The categories of Eylon and Linn (1988) and by Farnham-Diggory (1994) both provide valuable frameworks for identifying and describing main themes of science education research on learning and instruction over the past decades. They also appear to be suited to identifying trends of future development in this domain. Farnham-Diggory's three 'models' seem to be distinct at first sight but, in every real teaching and learning situation, there are facets of all three models included (Farnham-Diggory 1994, p. 467). Even constructivist approaches, which fall into the 'development' category, usually include 'training' of certain kinds when, for instance, terms or skills have to be learned. Cognitive apprenticeship approaches unavoidably incorporate issues that fall into the development model as soon as it comes to teaching and learning of certain science concepts and principles. We conclude that progress in teaching and learning science is not achieved when the three models of Farnham-Diggory are viewed as 'rival' approaches. We rather think that it is necessary to find out in which way the *three* models can be harnessed in intelligent ways to address the different facets of learning that science education includes.

Currently, there is an encouraging tendency towards an 'inclusive' view of science learning which brings together approaches of different theoretical orientations. In short, learning is viewed as conceptual development in much the same way as introduced by the seminal work of Piaget (1954). His idea of equilibration of assimilation and accommodation appears to be accepted still as a valuable perspective (Lawson 1994). Piaget also can be viewed as one of the 'fathers' of the variants of constructivism that dominated science education through the 1980s and the first years of the 1990s alike (von Glasersfeld 1995). At the heart of this constructivist view (Steffe & Gale 1995; Tobin 1993; Treagust, Duit & Fraser 1996) is the idea that the conceptions held by each individual guide understanding. A further key aspect of this view is that knowledge about the world outside is viewed as human construction. A reality outside the individual is not denied; rather, it is claimed only that all we know about reality is our tentative construction. Accordingly, learning is not viewed as transfer of knowledge but the learner actively constructing, or even creating, his or her knowledge on the basis of the knowledge already held. In addition, there are social aspects of the construction process; although individuals have to construct their own meaning of a new idea, the process of constructing meaning always is embedded in a particular social setting of which the individual is part. However, in mainstream constructivism in science education throughout the 1980s, there was undoubtedly a tendency to neglect social aspects of the construction process and emphasise the individual's construction instead. Social constructivist perspectives of various kinds that have gained growing attention in science education over the past years stress the significance of social aspects of knowledge construction (Hennessy 1993; Roth 1995; Metz's chapter in this *Handbook*). Undoubtedly these social perspectives have influenced the development and enrichment of the original constructivist view towards an inclusive view that incorporates both social and individual aspects alike.

The mainstream constructivist view of the 1980s and early 1990s, with its focus on qualitative understanding distinguished on the basis of personal theories and explanations and changes in learning that occur by perturbations created by teaching, falls into Farnham-Diggory's (1994) development model. On the other hand, social-constructivist perspectives, with their attention to the influence on the social milieu of knowledge construction, usually fall into her apprenticeship model. Another significant difference between the two constructivist positions concerns their view of knowledge in relation to the influence of the individual or social group on learning. In accordance with the leading cognitive science views of knowledge acquisition, mainstream constructivism has held that mental representations of certain structures or features of the world outside are stored in the human brain. Learning is seen as construction of mental models. Knowledge then is something an individual possesses. Social constructivist perspectives (e.g., Gergen 1995) do not deny that there is something stored in the human brain, but they claim that knowledge has significant 'social' aspects: knowledge can be distributed among the members of a certain community or shared by this community. Knowledge, then, is something that is 'between' the individual and the social.

THE ROLE OF PIAGETIAN IDEAS OF LEARNING IN SCIENCE EDUCATION

It is hardly possible to overemphasise the impact of Piaget's thinking, including his idea of stages of cognitive development, on our contemporary views of learning despite the many critiques of his approach. In order to do justice to Piaget's way of thinking about learning, it is necessary to take into consideration that his main concern was not psychological but epistemological (Bliss 1995). As Lawson (1994) argued, Piaget wanted to develop epistemology from a mere philosophical enterprise to an empirical domain. Piaget, therefore, has to be viewed as an empirical epistemologist who was interested in the development of knowledge in humans (compare Metz's chapter in this *Handbook*). His epistemological commitments were strongly influenced by Immanuel Kant, and can be called constructivist in the contemporary sense (Lawson 1994; von Glasersfeld 1995). Piaget's original training in biology influenced his views about knowledge construction in that he drew on analogies to adaptation of living beings to their environment. This orientation becomes most obvious in his distinction of assimilation and accommodation and the idea of equilibration which is the kernel of Piagetian thinking.

Assimilation is the process of the individual's adaptation to new sense impressions, with the inputs basically fitting the already-existing cognitive structure. On the other hand, accommodation indicates that, in the adaptation process, restructuring of the already-existing structure is necessary when the inputs do not fit existing cognitive structure. Assimilation and accommodation are always intimately interrelated; there is no assimilation without accommodation and vice versa. If the inputs do not fit, there is a disturbance of the mental balance or, in other words, a cognitive conflict. The balance can be restored by a process which Piaget calls equilibration, that is, by an interplay of assimilation and accommodation. It is easy to find this key Piagetian view in most contemporary constructivist approaches as discussed in the following section of the present chapter. This view also is the kernel of the influential instructional strategy of the 'learning cycle' (see Karplus 1977 and Abraham's chapter in this *Handbook*) which is based on Piagetian epistemology and which has been proven fruitful and successful (Lawson, Abraham & Renner 1989). If the learning cycle strategy is carefully analysed and compared to constructivist approaches of the 1980s that also deliberately employ cognitive conflict (Driver 1989), there are only marginal differences in instruction.

Piaget's stage theory, which has often been discussed and questioned, holds that there is a development of general thinking skills. There are four kinds of logical operations that children and adolescents exhibit in sequence: *sensorimotor* (about the first 18 months of life); *preoperational* (until about seven years); *concrete* *operational* (after about seven years); and *formal operational* (between 11 and 15 years). There is no doubt that the idea of general, logical thinking skills and their development in certain stages can be valuable in describing cognitive development, but there is a number of difficulties with Piagetian stage theory (Bliss 1995).

First, and foremost, the idea that logical thinking operations are independent from contexts has been seriously challenged. Research clearly showed that there is a strong domain-specific effect. In other words, the student's choice of logical operation depends on the particular science content and the problem's context. If an individual uses formal operational thinking in one domain, it is not certain that the same person would use that kind of thinking in other domains also (Seiler 1973). These findings, that have been supported by numerous studies, call into question not that general logical operations are of significance in learning science but that they are not universally transferred to other tasks once applied in certain tasks. Nevertheless, studies usually show significant positive correlations between Piagetian stages and science achievement (Lawson & Thompson 1988; Shayer & Wylam 1981). Shayer and Adey (1992) also demonstrated that deliberate training in Piagetian logical operations had some general impact in that accelerated learning occurred in content areas not included in the original training.

Lawson (1994, p. 163) provides a comprehensive critique of Piagetian stage theory. He claims that Piaget's belief that thinking patterns are isomorphic with rules of formal propositional logic is the most problematic position in his theory. He proposes to distinguish the terms *intuitive* and *reflective*, with 'reflective' replacing 'formal reasoning' in the Piagetian sense. The reflective adult is able to consider alternative theories and ask which is the most appropriate, whereas the intuitive thinker does not consider the relative merits of alternative theories.

In conclusion, Piagetian ideas still could provide powerful tools for thinking about learning (Bliss 1995). Piaget's view of knowledge acquisition as outlined by the equilibration process still appears to be widely accepted as a useful perspective. Even stage theory could provide valuable orientation if interpreted in a non-orthodox manner.

CONCEPTUAL CHANGE APPROACHES

'Conceptual change' has become a term that denotes key aspects of the mainstream constructivist approaches of the 1980s and early 1990s. Conceptual change approaches have their roots both in science education research (Duit in press; Posner, Strike, Hewson & Gertzog 1982) and in developmental psychology (Carey 1985; Vosniadou 1994). In the first case, conceptual change theory implies that students' conceptions need to be exchanged for the new science conceptions. This was at the heart of the Posner *et al.* (1982) framework. On the other hand, developmental research on conceptual change is usually descriptive and can only lead to recommendations for what to change or how to bring about conceptual change. Certainly the idea that context is an important variable in this process that needs to be taken into consideration is an important one, and not inconsistent with conceptual change research. As a consequence of this development and prominence, there are many slightly-different or even substantially-different meanings given to this term. Nevertheless, there seems to be some agreement among the key representatives of conceptual change approaches. The term conceptual change denotes that learning of science concepts and principles usually involves major restructuring of students' already-existing preinstructional conceptions. In other words, students' preinstructional conceptions and science conceptions are usually embedded in different qualitative frameworks.

Undoubtedly the term conceptual change is not well chosen as it invites a number of misinterpretations, among which is the idea that students' preconceptions have to be exchanged for the new science conceptions. In the late 1970s and the early 1980s especially, a predominant focus was that students' conceptions (often called 'misconceptions') have to be extinguished and replaced by the correct science view. Research has shown that this is not possible. Indeed, there appears to be no study which found that a particular student's conception could be completely extinguished and then replaced by the science view. Most studies show that the 'old' ideas stay 'alive' in particular contexts. Usually the best that could be achieved was a 'peripheral conceptual change' (Chinn & Brewer 1993) in that parts of the initial idea merge with parts of the new idea to form some sort of hybrid idea (Jung 1993; see also Chinn & Brewer's chapter in this *Handbook* for a discussion of intermediate stages in knowledge change). Further, extinction of old ideas is not only impossible but also undesirable. Many students' everyday conceptions – for instance, conceptions of the process of seeing, the propagation of light or heat phenomena – have proven fruitful and valuable in most everyday situations. The vast majority of adults (even scientists) successfully draw on such conceptions in everyday situations.

Conceptual change approaches therefore hold that the aim of science instruction is not to replace everyday views but to make students aware that, in certain contexts, science conceptions are much more fruitful than their own conceptions. Ideas of 'situated cognition' (Brown, Collins & Duguid 1989) have substantially supported this view of context dependency of conceptions (Hennessy 1993) and it is claimed that every cognition and every learning event is situated (see below). The situated cognition perspective provides a valuable framework for describing and understanding research findings which show that change does not come easily and is limited to particular contexts (Tytler 1994). In relation to context dependency, Hewson and Hewson (1992) view conceptual change as change of status given to the old and the new conceptions: old students' conceptions lose status at the same time that the new science conceptions gain status.

Learning Pathways – Conceptual Change Versus Conceptual Growth

The key assumption of conceptual change approaches is that learning has to start from certain already-existing conceptions and that learning pathways (Scott

1992) have to be designed so that they lead from these preconceptions towards the science conceptions to be learned. Learning pathways can be described as being continuous or discontinuous. Continuous pathways of teaching/learning try to avoid the fundamental restructuring that is necessary in the case of the discontinuous pathways of teaching/learning. One kind of instruction using a continuous pathway starts from aspects of students' preinstructional conceptions or frameworks that are at least in part compatible with the science view to be achieved. From there, a basically continuous passage of learning is possible. A second continuous learning pathway is that of 'reinterpretation' (Jung 1986); the strategy is different in that the starting point is a set of students' conceptions that appear to be in contrast to science conceptions. Key facets of the students' conceptions, then, are reinterpreted in such a way that they are basically in accordance with the science conceptions.

In contrast to the above teaching/learning approaches, discontinuous pathways deliberately draw on the conflict between students' conceptions and science conceptions. Cognitive conflict, therefore, is a significant tool in these pathways (Scott, Asoko & Driver 1992). There are three primary kinds of cognitive conflict: students are asked for predictions and then are challenged by the conflicting results of an experiment; there is a conflict between students' and the teacher's ideas; and there is a conflict between the ideas of different students. The theoretical orientation of cognitive conflict usually is Piaget's idea of restoring mental equilibrium by intimate interplay of assimilation and accommodation (Lawson 1994; Rowell & Dawson 1985). Reference also is given to Festinger's (1962) theory of cognitive dissonance (Driver & Erickson 1983). The crucial issue in cognitive conflict strategies is that students need to 'see' the conflict. What appears to be clearly discrepant from the perspective of a teacher can be viewed as only marginally different or might not be considered discrepant at all from the perspectives of the students.

When the issue of conceptual change versus conceptual growth is debated, two features are not given sufficient attention. First, even when students' everyday conceptions and science conceptions are in stark contrast, it is not absolutely necessary to start from these conceptions. It is not even necessary to bring these everyday conceptions explicitly into play in instruction. There are possibilities of finding 'intelligent' teaching/learning pathways that initially bypass, so to speak, students' conceptions of the phenomena affiliated with the science concepts and principles to be learned. In such cases, learning pathways start with general thinking schemata (or with conceptions that are not in contrast with the science view) and they lead to the science conceptions, perhaps via analogies (see Chinn & Brewer's chapter in this *Handbook* for a discussion of how old knowledge is used to construct new knowledge). Second, conceptual growth and conceptual change should be viewed as complementary terms. In every learning pathway from students' conceptions towards science conceptions, there are facets that can be indicated by the two poles of that complementarity (see the previous remarks on the intimate interplay of assimilation and accommodation in Piagetian theory). Studies of learning processes have clearly shown that real learning pathways are very complex and cannot adequately be described by just conceptual growth or conceptual change (Duit, Goldberg & Niedderer 1992; Niedderer 1996). They are quite different for different students of the same groups. Usually, there are 'backwards and forwards' movements, 'dead-end streets', parallel developments and the like. Tytler (1994, p. 311) therefore considers that terms like conceptual change (he uses the term 'theory exchange') can only be useful in describing the thinking of student cohorts. These terms might offer insight into difficulties in attaining new concepts, but they do not offer much explanatory insight into the process of individual construction of understanding.

It is somewhat difficult to come to a clear-cut conclusion regarding the success of conceptual change approaches. A key difficulty is that these approaches often include fundamental restructuring of more traditionally-oriented science instruction. Conceptual change strategies, in other words, often are only one facet within approaches that aim at making science instruction understandable and fruitful for the students in a very comprehensive way. Therefore, it is difficult or even impossible to compare the new approaches with others. All that is possible, then, is to investigate whether conceptual change approaches achieve the aims which they intend. In reviewing advantages and problems of the mainstream constructivism of the 1980s and early 1990s in science education, Solomon (1994) is rather sceptical. However, Wandersee, Mintzes and Novak (1994) come to a much more optimistic conclusion from an analysis of 103 conceptual change studies. Although they found a number of methodological limitations in several studies, they concluded 'even with the aforementioned caveats in mind, we remain impressed by the relative success some researchers have achieved today' (Wandersee *et al.* 1994, p. 192). Guzetti, Snyder, Glass and Gamas (1993) carried out a meta-analysis of 70 of studies of intervention strategies in science education and in science-related reading education. They included only studies that incorporated quantitative measures comparing treatment and control groups. For this reason, key constructivist conceptual change approaches, such as the Children's Learning in Science (CLIS) project in Leeds (Driver 1989; Scott & Driver's chapter in this *Handbook*) were not included. Guzetti *et al.* (1993, p. 149) concluded: 'Based on the accumulated evidence from two disciplines [reading and science education], we have found that instructional interventions designed to offend the intuitive conception were effective in promoting conceptual change. The format of the strategy (e.g., refutational text, bridging analogies, augmented activation activities) seems irrelevant, providing the nature of the strategy includes cognitive conflict.'

The Conceptual Change Theory

The most influential theory of conceptual change was developed by a group of science educators and philosophers of science at Cornell University (Hewson 1981; Posner *et al.* 1982; Strike & Posner 1985). The theory has become 'very popular and useful' (Pintrich, Marx & Boyle 1993, p. 169) in science education as well as in a number of other fields, and has been extensively applied and subsequently changed (see the review by Hewson & Thorley 1989). According to the theory, there are four conditions that foster conceptual change. There must be dissatisfaction with current conceptions and any new conception must be intelligible, initially plausible and fruitful.

The theory provides answers to the question: 'How do learners make a transition from one conception, to a successor conception?' The transition is conceptualised in Piagetian terms as equilibration of assimilation and accommodation. The theory establishes analogies between conceptual development in science and in individual learners. The four conditions for conceptual change are derived from the work of philosophers and historians of science, especially Kuhn (1970), Lakatos (1970) and Toulmin (1972). The metaphor of the student (or the child) as scientist, which also is a leading metaphor in several other constructivist approaches, therefore plays a significant role in conceptual change theory [see Driver's (1983) 'pupil-as-scientist' perspective which is reminiscent of Kelly's (1955) idea of 'man-the-scientist']. Another key characteristic of the theory is the term 'conceptual ecology' which denotes that the already-existing cognitive structure of the learner is a system of closely interrelated items which, in several respects, is reminiscent of interactions in eco-systems.

In critically analysing their 1982 theory, Strike and Posner (1992) suggest that the initial theory put too much emphasis on the rational and neglected affective and social issues of conceptual change. They also claimed that students' conceptual ecology should be viewed much more in terms of a dynamic system than as in the initial theory. There, the interaction of prior conceptions and the new conceptions was not sufficiently acknowledged.

Pintrich *et al.* (1993), in addressing deficiencies of the initial theory of conceptual change by Posner *et al.* (1982), use the thermal metaphor of 'cold' to denote their reservation about overly rational approaches and 'cognition only' models of students' learning. The theory of conceptual change, according to the authors, is too much oriented to rational aspects in two ways (compare the critique by Strike & Posner 1992). First, it is based on a philosophy of science perspective that places major emphasis on rationality, or the significance of logical arguments in the process of conceptual development. Compared with the approaches by Kuhn, Lakatos and Toulmin, more recent developments in the philosophy of science (e.g., social constructivist approaches like the one by Knorr-Cetina 1981) have pointed out that manifold 'non-rational' issues play a role also. Second, the rational is also overemphasised in the process of conceptual change in individuals from their initial preinstructional conceptions to the science concepts. The key metaphor of the initial theory of conceptual change, the student as scientist, is undergoing rigorous discussion (Caravita & Halldén 1994). It is questionable that this metaphor in fact provides valuable analogies for understanding the process of conceptual change. The learning communities in science classrooms and the scientific community are very different in that they operate on the grounds of fundamentally different aims and within fundamentally different institutional conditions. For instance, schools are much more driven by the need to maintain bureaucratic and institutional norms rather than scholarly norms. O'Loughlin (1992) constructed a similar critique against constructivist approaches in stating that the culture in science classrooms, with its power structures and discourses, is not adequately taken into account.

In summarising this line of critique, conceptual change has to be viewed as a process of bewildering complexity that is dependent on many closely interrelated variables. Conceptual change, the process of conceptual development from students' prior ideas towards science concepts, has to be embedded in 'conceptual change supporting conditions', including the motivation, interests and beliefs of learners and teachers as well as classroom climate and power structures.

Resistances to Change

Learning of key science concepts and principles is difficult because there is resistance to conceptual change due to everyday experiences, possible biological predispositions, and the complexity of the learning task. Learning science is especially difficult in fields in which students' preinstructional conceptions are deeply rooted in daily life experiences. Conceptions that are based on empirical evidence through sense experiences (like the process of seeing, thermal phenomena, and conceptions of forces and motions) fall into this category as do everyday ways of speaking about natural and technical phenomena. A further resistance to change is a biological predisposition to interpret empirical evidence in ways related to how the human mind has evolved. Vosniadou and Brewer (1992) introduced the term of 'entrenched' belief in the sense that beliefs are presuppositions organised in complex interrelated structures. They explicitly go beyond science content and include conceptions like 'ontological beliefs' (i.e., beliefs about fundamental categories and properties of the world) and 'epistemological commitments' (i.e., beliefs about what scientific knowledge is and what counts as good scientific theory).

The initial theory of conceptual change by Posner *et al.* (1982) provides explanations of why conceptual change often is so difficult. If a conception is deeply rooted (entrenched) and has proven successful in most previous daily life situations, there is no dissatisfaction with this conception. Further, if there is no conception available that is intelligible and plausible from a student's perspective, a change is most unlikely. Students are frequently unable to understand the new theory, because their old conceptions provide the interpretation schemata, the goggles so to speak, for looking at the new science conceptions. Hence, the new conceptions do not become intelligible and plausible to students, who are unable to understand the new view because they do not posses sufficient 'background knowledge' (Chinn & Brewer 1993; Schumacher, Tice, Wen Loi, Stein, Joyner & Jolton 1993; Strike & Posner 1985). Without a certain amount of background knowledge, the arguments in favour of the new conceptions might not be understood. There is a certain dilemma which has similarities to Bereiter's (1985) learning paradox that a new conception becomes understandable only if there is already some knowledge about that conception available. The condition of 'intelligible' does not 'guarantee' conceptual change. There are several cases in the literature of students understanding a new theory but not believing it (e.g., Jung 1993).

Schumacher *et al.* (1993) discuss motivational factors that impede conceptual changes and claim that, 'if a misconception is held in an area where students have little interest, they will be unlikely to invest the cognitive resources' (p. 4). In other words, dissatisfaction substantially depends also on affective features. These authors review research on resistance to change in several domains such as studies of human judgement and decision making, psychotherapy and attitude change. They conclude that resistance to change as found in science misconceptions appears to be a very common human trait. There usually are important benefits to having stable conceptions, beliefs or attitudes. These conceptions, beliefs and attitudes have been formed by the individual in processes of adaptation to life-world experiences and usually provide valuable frames for behaviour. To give them up usually is a loss of stability for the students.

Chi, Slotta and de Leeuw (1994) developed a theory of conceptual change for learning science concepts. It assumes that conceptual change occurs when a concept has to be reassigned to an ontologically distinct category. They distinguish the three 'trees' of categories of 'matter' (or things), 'processes' and 'mental states', and they provide examples across the sciences for which learning of key concepts includes changes of ontological categories. They hold that the most difficult concepts to be learned require a change of ontological categories. There is no doubt that, when students have severe difficulties in accepting science concepts, a change of an ontological category often is necessary. The physics concept of force, for instance, falls into the category of relations between objects (namely, interactions) and not into the category of properties of things as in daily life. Here force is usually seen as something that strong humans and animals possess. Chi *et al.* (1994) therefore point to important barriers to learning science concepts but their present theory is limited (Duit 1995). First, their choice of categories is somewhat arbitrary. The ontological change in the case of the concept of force needs a more elaborated set of categories than the three categories used, namely, the change from a property of objects to relations between objects. Second, learning of key science concepts often is not adequately described by such changes from one category to another. In the case of heat concepts, the undifferentiated heat concept of daily life has to be differentiated and unfolded into the concepts of temperature, heat energy, internal energy and entropy. The naive everyday concept of heat includes facets of all of the aspects indicated by the physics heat concepts mentioned (Kesidou, Duit & Glynn 1995). Third, Chi *el al.* argue at the level which Pintrich *et al.* (1993) call 'cold' conceptual change, and they do not consider affective issues. Fourth, the theory presents only a syntactic, not a semantic, explanation of conceptual change (Vosniadou 1994). Therefore, the perspective of entrenched beliefs in the above meaning appears to be a more inclusive position because it includes not only ontological changes of the type that Chi *et al.* discuss, but also changes of a broader nature.

There are many studies of students' science conceptions which indicate that counter-evidence does not necessarily change students' points of view, as is explicitly or implicitly assumed in many teaching and learning approaches that emphasise cognitive conflict. A paradigmatic example stems from a study by Tiberghien (1980). A 12-year-old girl is asked to find out if an ice block wrapped in aluminium foil will melt faster than an ice block wrapped in wool. The girl believes that the iceblock wrapped in wool will melt first, because wool is warm and therefore will give heat to the ice. When the ice block wrapped in aluminium foil melts first, the girl's initial conception is not shaken and she invents a number of protective arguments in favour of her idea.

Chinn and Brewer (1993) provide a review of the role of anomalous data in knowledge acquisition, especially in science. They describe seven ways in which students deal with discrepant evidence by ignoring anomalous data; by rejecting anomalous data; by excluding anomalous data; by holding anomalous data in abeyance; by reinterpreting anomalous data; by peripheral theory change; and by theory change. They also discuss conditions under which anomalous data can occur and identify how people respond to anomalous data. Among these are characteristics of the prior knowledge like its 'entrenchment', ontological beliefs, epistemological commitments and, as previously mentioned, background knowledge (see also Chinn & Brewer's chapter in this *Handbook*).

INDIVIDUAL AND SOCIAL CONSTRUCTION – SOCIAL-CONSTRUCTIVIST ISSUES OF LEARNING

As outlined above, there is a growing line of critique against mainstream 'conceptual change' approaches in science education that address the tendency to overemphasise the individual's learning and neglect social issues in knowledge-construction processes, and to view knowledge primarily as something stored in the individual mental system, as mental models of the world outside. Marton (1986) developed a phenomenological counterposition to mainstream constructivist perspectives which he calls a 'phenomenographic approach' (Lybeck, Marton, Stroemdahl & Tullberg 1988; Rennstroem 1987). He distinguishes between a 'mental model based perspective' and an 'experientially based perspective' of conceptions. The first perspective views conceptions as mental representations (i.e., as tangible constructs in the learner's head), whereas the latter perspective depicts conceptions as being characterisations of categories of descriptions reflecting person-world relationships. From the perspective of mainstream constructivism, conceptual change takes place within a person's head. From the phenomenographic perspective, conceptual change is achieved by changing one's relationship with the world. In discussing 'challenges to conceptual change' from the phenomenographic perspective, Linder (1993) emphasises that students need to develop meaningful relationships with the new conceptions in particular contexts. He concludes that less emphasis should be put on:

> . . . efforts to change segments of students' existing repertoires of conceptualizations and more efforts on enhancing students' capabilities to distinguish between conceptualizations in a manner appropriate to some specific context – in other words, being able to appreciate the functional appropriateness of one, or more, of their conceptions in a particular context, making science education into a functional base from which to view the world. (Linder 1993, p. 298)

Similar views have been developed within social-constructivist approaches which draw, not only on phenomenological ideas, but also on the work of Vygotsky (1986) and the Soviet school of activity theory based on Vygotsky's work (Wertsch & Toma 1995; Metz's chapter in this *Handbook*). Other sources are social-constructivist studies of the genesis of knowledge in scientific communities (Knorr-Cetina 1981) and empirical studies of everyday mathematics and science (Lave & Wenger 1991). In social-constructivist approaches that have been employed in science education, the idea of situated cognition usually plays a key role (Hennessy 1993; Roth 1995). Brown, Collins and Duguid (1989) describe the basic ideas of situated cognition as follows:

> The activity in which knowledge is developed and deployed, it is now argued, is not separable from or ancillary to learning and cognition. Nor is it neutral. Rather, it is an integral part of what is learned. Situations might be said to co-produce knowledge through activity. Learning and cognition, it is now possible to argue, are fundamentally situated. (p. 32)

From the perspective of situated cognition, learning means change from one sociocultural context, usually the everyday context, to a new, science context or, in other words, changes from the practice of one culture to another (for crossing between cultures, see Cobern & Aikenhead's chapter in this *Handbook*). As language is a key aspect of culture in the sense used here, science learning also is viewed as change of languages or change of language games. Learning science means to learn 'talking science' (Lemke 1990). 'Authentic' learning situations according to Roth (1995) are dominated by open-inquiry activities and play a key role in change in classrooms. 'Cognitive apprenticeship' is often seen as the best method for introducing the learner into the new culture as the expert guides the apprentice (the novice). By developing participation in activities within the community in question, step-by-step the apprentice becomes a member of that community. The metaphor of apprenticeship provides a different flavour to the continuous and discontinuous learning pathways in conceptual change approaches. The process of acculturation, the slowly growing understanding, in numerous hermeneutical circles can be viewed as a promising counter-position to conceptual change strategies which sometimes appear to be instructional engineering. Briefly summarised, situated cognition, authentic learning situations and cognitive apprenticeship are closely interrelated.

Social-constructivist ideas have gained growing attention in science education over the past years. On the one hand, there are attempts to employ these ideas to address limitations and one-sidenesses of mainstream constructivist approaches and to further develop them (Anderson, Belt, Gamalski & Greminger 1987; Scott 1995; Ueno & Arimoto 1993). On the other hand, there is a number of studies that explore the potential of the social-constructivist perspective to investigate and support meaning construction in learning communities. Roth's (1994) work on open experimenting in science instruction and his studies on collaborative design (McGinn, Roth, Boutonné & Woszczyna 1995) could be taken as examples (see Tytler 1994 for a discussion on the social-constructivist perspective as a theoretical framework for interpreting students' learning processes in science). Clearly, the focus of empirical research is studying collaborative meaning construction and learning (i.e., guided inquiry in small groups). In this field, the potential of the social-constructivist views of knowledge becomes obvious as being 'distributed' and 'shared' rather than being the property of individuals.

To view learning science as change from one culture to another, or as initiation into a new culture, opens avenues that appear to go beyond making science learning merely more effective. For example, Cobern and Aikenhead (in this *Handbook*) provide a broad view of what they call 'cultural aspects of learning science'. Their approach is based on the social-constructivist perspective but is given particular characteristics by two aspects. The first is the idea of 'anthropological' learning (Aikenhead 1996) which involves viewing science learners as anthropologists who enjoy, and are capable of, constructing meaning out of the foreign culture of science. The second aspect is a view of 'crossing over' between an everyday life culture to the science culture in societies or parts of societies for which the everyday culture is far from being science and technology-oriented (e.g., Aborigines and Native Indians). Science learning in science-oriented 'Western' societies can be viewed as analogous to that kind of 'crossing over' in non-Western cultures where deep-rooted difficulties of learning science go far beyond the issues of knowledge construction.

CONCLUSIONS

Domain-specific preinstructional knowledge has proven to be *the* key factor determining learning and problem solving in research in all science domains. Ausubel's (1968, p. vi) famous dictum, 'The most important single factor influencing learning is what the learner already knows . . .', has been corroborated many times since it was written. Although this dictum concerns learning science in a particular way based on what the learners already know, science instruction frequently is not designed for the science perspectives to be learned effectively. This is true for science content (i.e., for science concepts and principles) and for science epistemologies and ontologies (i.e., for views on the nature of science). Learning science is only successful if learning pathways are designed to lead from certain facets of preinstructional knowledge towards the science perspective.

The conceptual change approaches to learning which are critically reviewed in this chapter must be considered whenever science instruction is designed. Conceptual change strategies of some kind have to be embedded in what has been called 'conceptual change supporting conditions' which incorporate issues such as students' interests, motivation and self-concepts, or the classroom climate and power structures in school. Social constructivist views of learning appear to contribute primarily to the provision of such conceptual change supporting conditions. It is an important challenge for science education research on learning and instruction in the future to investigate relations between issues of conceptual change (of designing adequate learning pathways) and the many supporting conditions. Little research knowledge is available on this so far. Only during such a process of further development and refinement of the inclusive view, will it be possible to see whether the implementation of this view actually leads to more effective learning than using previous, more limited views. The inclusive, social constructivist view of learning appears to be suited also to guiding our thinking about science education beyond the aim of making science teaching and learning more effective. It could lead to an inclusive view of science education in a much broader sense in that it also incorporates considerations of future aims of science instructions.

The views of learning science discussed in the present chapter all are on a 'macro' or phenomenological level. The rapid advances in the neuro-sciences regarding the structure and function of the human brain so far have not contributed substantially to views of effective learning. In underpinning key facets of his revised Piagetian view of learning with recent findings on the architecture of the human brain, Lawson's (1994) attempt to provide a 'micro' view of learning by referring to neurological issues is an exciting first step that appears to provide promising insights for the future. However, at the moment, it seems that the explanatory and predictive power of the 'neuro' view is still too limited to contribute to the development of powerful teaching and learning strategies.

The other seven chapters of this section of the *Handbook* on Learning provide a comprehensive picture of the essential areas that we believe are important in understanding learning in science classrooms: language and science; cultural aspects of learning science; learning science through models and modelling; learning about science teaching; what young children can be expected to know about science; theories of knowledge acquisition for identifying gaps in our knowledge as well as guiding teaching; and students' representation of the nature of scientific knowledge.

In the chapter entitled 'New Perspectives on Language in Science', Sutton explores the relationship between language and learning in science by arguing that the impersonal nature of today's scientific writing does not help students connect their scientific understanding with their own human concerns and those of other people. As well as providing illustrations of historical changes in science writing, Sutton makes recommendations for introducing a personal voice back into science and what is meant by communication.

In their chapter, entitled 'Cultural Aspects of Learning Science', Cobern and Aikenhead provide a cultural perspective on science education, illustrate it with examples from secondary science on how students' culture can affect their learning of science, and identify related issues for teaching and research. The authors show how, for many students in school, learning science is not a straightforward process but often involves a variety of cultural border crossings.

Gilbert and Boulter examine 'Learning Science Through Models and Modelling' and show how models can and do contribute to learning in classrooms and other contexts. A major aspect of this chapter is a description of the use of models and narratives in the classroom and in other contexts involving computers, educational television and museums.

In their chapter, entitled 'Learning About Science Teaching: Perspectives From an Action Research Project', Scott and Driver provide an account of an action research project whose aim was to draw upon a constructivist view of learning in developing approaches and materials for teaching particular concepts in high school. The chapter focuses on curriculum design and pedagogy, as well as the nature of the teachers' involvement in the project.

In her chapter entitled 'Scientific Inquiry Within Reach of Young Children', Metz examines emergent literature about the process and products of children's scientific inquiry, children's domain-specific knowledge and children's collaborative cognition. This literature shows that children between six and 13 years of age can engage in independent empirical investigations. While the literature has gaps for older children and adults and includes some inadequate experimental designs, it supports both fruitful theory construction and improvement of the inquiry process itself.

The chapter by Chinn and Brewer entitled 'Theories of Knowledge Acquisition' analyses the problem of knowledge acquisition and presents eight core questions that are the basis of a framework for assisting researchers, theorists and teachers to identify the gaps in current knowledge. The chapter shows that there is a wide range of theoretically-important questions that have not been adequately investigated and that teachers could develop more effective instruction if better answers existed.

The epistemology of school science is the issue addressed by Désautels and Larochelle in their chapter entitled 'The Epistemology of Students: The "Thingified" Nature of Scientific Knowledge'. The authors show that an understanding of the nature of models, laws and theories appears to change little as a result of schooling and that empirical perceptions of scientific phenomena dominate over theoretical and personal perspectives. A major feature of students' epistemologies of science is the tendency for students to give science a material entity.

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4.4 Science Curriculum: Transforming Goals to Practices

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Within a short period of 25 years, science educators developed perspectives that have expanded from national to global dimensions. We are indeed in a global revolution in science, mathematics and technology education (Organisation for Economic Cooperation and Development 1996). No doubt this developmental change relates to advances in science and technology, especially those involving transportation and communication. But, like most changes, new issues and problems emerge. In science education, one of those new issues is a need to reform the curriculum.

Although reform must include changing multiple facets of science education, such as teaching and assessment, clearly the curriculum emerges as a central focus of any reform effort. Considering global perspectives and science curriculum reform engages the problem that forms the theme of this chapter: 'How can educators both reform the science curriculum to achieve the common goal of scientific literacy and accommodate the unique needs and aspirations of their region or nation?' The subtitle of the chapter anticipates the answer to the question. Once science educators have identified and clarified the curriculum's goals for scientific literacy, the critical issue becomes the transformation of those goals to policy, programs, and practices. Associated with any answer to the question is the use of resources, which include those human and material aspects that can be used for support or help when needed. What are the available resources for designing and developing a science curriculum? Answers to this question define the possibilities and limits of curriculum reform and they are certainly unique to a region or nation.

The perspectives developed in this chapter are based on presentations from the curriculum strand at an international conference entitled *International Conference on Science Education in Developing Countries: From Theory to Practice* held in Israel in 1993. To provide coordination and coherence among the presentations at that conference, we developed an organisation that generally parallels (with critical additions) the conference sub-theme of 'Transforming Goals to Practices'.

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SCIENTIFIC LITERACY AND THE SCIENCE CURRICULUM

The process of curriculum reform must begin with, and be informed by, the larger and more comprehensive purposes on which science educators from diverse countries can find common agreement. During the conference, the goal of scientific and technological literacy transcended the unique requirements of more-developed and less-developed countries. Presentations by Haggis (France), Cobern (USA), Whittle (Malawi), D'Ambrosio (Brazil) and Roseman (USA) developed the important first step of curriculum reform, namely, the reappraisal and reformulation of goals so that they represent the contemporary perspective of scientific literacy.

David Layton, Edgar Jenkins and James Donnelly, from the University of Leeds, Great Britain, completed a comprehensive, international review of scientific and technological literacy for UNESCO (1993). A careful review of this thorough summary of the literature clarifies the meaning of scientific literacy. In this chapter, instead of attempting a thorough review of scientific literacy, we describe some important aspects of scientific literacy for the science curriculum. We largely based this discussion on the aforementioned review by Layton, Jenkins and Donnelly (1993) and *Achieving Scientific Literacy: From Purpose to Practice* (Bybee 1997).

Using the term 'scientific literacy' implies a general education approach for the science curriculum. General education suggests that part of a student's education that emphasises an orientation towards personal development and citizenship. A general education orientation contrasts with a specialised education that emphasises competence in a specific career or occupation, such as science. Assuming a general education orientation for the science curriculum suggests that one should begin the design of a program by asking what it is that a student ought to know, value, and do as a citizen.

We contrast this approach to designing a science curriculum with an initial effort in which individuals ask what it is about physics, chemistry, biology and the earth sciences that students should learn. We view the science-technology-society (S-T-S) approach to science curriculum as a means of introducing the general education idea within the general purpose of achieving scientific literacy.

Closely associated with scientific literacy is the recommendation that educators design science curriculum materials for *all* students. Peter Fensham, an Australian science educator, has written several thoughtful essays on the topic of science education for all students (Fensham 1985, 1986/87, 1988). Paralleling the discussion on general education, Fensham clearly differentiates the demands of teaching science for future scientists from the goal of a scientifically literate citizenry. The 'scientific literacy' and 'science for *all*' themes are complementary. Fensham (1985) provides a useful metaphor to help developers realise the difference between a science curriculum for future scientists and one for all students. The former views science internally, presenting science as scientists see it; the latter views science externally, from the perspective of someone in society. From the perspective described here, science should be organised and taught in a context that continually affirms a personal and social perspective.

It is more beneficial to think of the aforementioned components of scientific literacy as goals towards which all individuals can develop for a lifetime. Indeed, one can define goals or thresholds for purposes of curriculum and instruction. The business of science education ought to be the continual development of individuals' understandings and abilities within the components described above.

Within the components of scientific literacy, one also has to represent a variety of expressions of understandings and abilities. For example, individuals probably can use scientific terms correctly, but most agree that equating scientific literacy with vocabulary represents a lack of understanding of the idea of scientific literacy. Figure 1, based on the work of Bybee (Biological Sciences Curriculum Study 1993; Bybee 1995, 1997; Uno & Bybee 1994), presents different aspects of scientific literacy that could be helpful to those designing science curricula.

RETHINKING GOALS FOR THE SCIENCE CURRICULUM

The history of science teaching reveals several common goals for students and that historical changes are primarily shifts in emphasis among the goals rather than the creation of entirely new goals. Thus, studying the history of science education, in particular the changing structure and function of goals, provides insights for curriculum developers today. Extended historical reviews of the goals of science teaching include *A History of Ideas in Science Education* (DeBoer 1991), *Reforming Science Education* (Bybee 1993) and the chapter entitled 'Goals for the Science Curriculum' in *Handbook of Research on Science Teaching and Learning* (Bybee & DeBoer 1994).

Throughout the history of science education, three major goals for students have been (1) to acquire scientific knowledge, (2) to learn the procedures or methodologies of science and (3) to understand the applications of science, especially the relationship between science and society. The terms used to express these goals have changed throughout history. Scientific knowledge, for example, has been called facts, principles, conceptual schemes and major themes. Scientific procedures have been referred to as the scientific method, problem solving, scientific inquiry and the nature of science. Also, for a long time, there has been confusion between an emphasis on *knowing* about the procedures of science and *doing* scientific investigations. The applications of science have found expression as life adjustment, science personpower shortage and the contemporary science-technology-society (S-T-S) movement. In the following discussion, we use the terms 'scientific method', 'knowledge' and 'applications' broadly and generically to encompass the variety of terms used by science educators.

Sometimes the goals of scientific knowledge, method and applications are accompanied by clearly articulated justifications, but at other times they are advanced and accepted less critically. Science educators periodically should examine goals and their representation in science programs. Science programs will represent a curricular emphasis (Roberts 1982) – the structure and function of goals. Science educators should decide why they hold the views which they do and if they

This framework presents scientific and technological literacy as a continuum in which an individual develops greater and more sophisticated understanding of science and technology. This framework functions as a taxonomy for extant programs and practices and as a guide for curriculum and instruction.

Nominal Scientific and Technological Literacy

Individuals demonstrating *nominal* literacy associate vocabulary with the general area of science and technology. However, the association represents a misconception, naive theory or inaccurate concept. Using the basic definition of nominal, the relationship between science and technology terms and acceptable definitions is small and significant. There is, at best, only a token understanding that bears little or no relationship to real understanding.

Functional Scientific and Technological Literacy

Individuals demonstrating *functional* literacy respond adequately and appropriately to vocabulary associated with science and technology. They meet minimum standards of literacy. That is, they can read and write passages with simple scientific and technological vocabulary. Individuals might associate vocabulary with larger conceptual schemes, for example, that genetics is associated with variation within a species and variation is associated with evolution, but with token understanding of associations.

Conceptual and Procedural Scientific and Technological Literacy

Individuals demonstrate *conceptual and procedural* literacy by an understanding of both the parts (e.g., facts and information) and the whole (e.g., concepts, structure of a discipline) of science and technology as disciplines. Further, the individual can identify the way the parts form a whole *vis a vis* major conceptual schemes and the way new explanations and inventions develop *vis a vis* the processes of scientific inquiry and technological design. These individuals understand and can use the structure of scientific disciplines and the procedures of inquiry and design for developing new knowledge and techniques.

Multidimensional Scientific and Technological Literacy

Multidimensional literacy consists of understanding the essential conceptual structures of science and technology plus understanding features that make that understanding of the disciplines more complete, for example, the history and nature of science. In addition, individuals at this level understand the relationship of disciplines to the whole of science and technology, to society and to contemporary science-related and technology-related social issues.

Figure 1: A framework for scientific and technological literacy

can justify the particular emphasis in light of contemporary societal demands. This examination enables them to justify their focus and determine specifically what they mean by each of these major goals in curriculum design.

Reasons for teaching science knowledge, methods and applications have included (1) enhancing personal development, which includes aesthetic appreciation, intellectual development and career awareness, (2) maintaining and improving society, which includes the maintenance of a stable social order, economic productivity and the preparation of citizens who feel comfortable in a scientific and technological world, and (3) sustaining and developing the scientific enterprise itself. This enterprise involves the transmission of scientific knowledge from one generation to the next (so that each subsequent generation has a knowledge base from which new scientific discoveries can be made) and the formation of a scientifically enlightened citizenry sympathetic to the importance of science as a field of inquiry.

The challenge for science educators now, as in the past, is establishing an appropriate balance among competing goals given today's social needs. Recently, more than ever before, there is recognition of the potential relationship between the three major goal areas and this allows us to balance our curriculum focus on scientific knowledge, method, and applications without viewing the goals as mutually exclusive and thus diminishing our support for any one of them. In the following paragraphs, we briefly examine the goals of scientific knowledge, methods, and applications for the curriculum.

In primary and secondary schools, the main reason for teaching science today is the same as it has been in the past – to give students an understanding of the natural world and the abilities to reason and think critically as they explain their world. Students should begin early with observing and describing the world around them and moving towards progressively more elaborated scientific explanations of phenomena. By the end of high school, students should be able to provide comprehensive explanations for the most obvious and compelling events that they experience, such as the seasons, day and night, disease, heredity and species variation, and dangers of hazardous substances.

With respect to the methods of science, students should learn a disciplined way of asking questions, making investigations and constructing explanations of a scientific and technological nature. The latter certainly can be developed in a personal/societal context. Students should learn that scientific inquiry is a powerful, but not the only, route to progress in our world. Inquiry should not be taught in isolation but as a tool for finding answers to questions about the world in which students live. Science curricula and teaching consistently should emphasise students' conceptual development of scientific explanations, as opposed to step-by-step methods that too often characterise the nature of scientific inquiry.

Concerning the applications of science, students should confront contemporary and historical examples of how scientific knowledge is related to social advances and how society influences scientific advances. Once again, the focus should not be on learning about science and society for their own sakes, but to bring students to an appreciation of the complexity of the scientific/technological enterprise and to provide contexts and explanations for important science-related and technology-related societal challenges which they confront.

Scientific knowledge, method, and applications should not be taught in isolation. Each needs to be taught in connection with the other, with the aim of enlarging students' understanding of their world in meaningful ways.

Scientific literacy expresses the configuration and balance of goals for science education and thus the design or review of curriculum should assess the degree to which the curriculum incorporates the acquisition of scientific knowledge, development of inquiry abilities and understanding of the applications of science. To what degree and in what form are the goals expressed? Does the curriculum suggest one orientation for the structuring of the goals or does it suggest variations in the structuring of goals? Are there guidelines or suggestions for the use of goals in the design of curriculum materials, teaching strategies and assessment practices? If the curriculum were achieved, what levels and types of scientific literacy would be developed for the constellation of components described earlier? Would individuals continue into careers associated with science, engineering and related work?

Science curriculum developers should continue to work towards an integration of the three major goals of acquiring scientific knowledge, developing the abilities of scientific inquiry, and applying the understandings and abilities of science to personal decisions and societal challenges. If developers do, students' lives will be enriched, the levels of scientific literacy will be heightened, and the sympathy towards science as a way of knowing will be enlarged. More students will pursue careers in science and engineering, and we should continue to develop the understanding and skills required to solve our most vexing problems.

TRANSFORMING GOALS TO A FRAMEWORK FOR CURRICULUM AND INSTRUCTION

An essential step, and one that is neglected too often, consists of the translation of goals into a curriculum framework and the need to address the critical issues in design and development of new science curricula. The framework specifies and explains the basic components used to design the science program. In the past, it was common for a curriculum framework to specify only criteria for content selection. Little, if any, attention was paid to a learning-teaching model and few curriculum developers attended to assessment practices. A complete framework provides information needed to make decisions about the content, the scope and sequence of activities, the selection of effective instructional strategies and techniques, appropriate assessment practices and other specifics of the curriculum. At a minimum, a framework defines enough of the science curriculum to differentiate it from other science programs.

Using a technological metaphor, a framework provides the requirements and specifications for a design project. The framework has to fulfil certain criteria and acknowledge constraints. At the same time, the more specific details must be left to those who actually will develop the science curriculum. Although there will be modification as the curriculum framework actually is developed and implemented, there should be fidelity to the original intentions, specifications, constraints and overall design.

A framework has advantages and disadvantages. An advantage of the framework is that program developers at local, state and national levels have opportunities to provide specific ideas. One assumes those decisions would be made in terms of the unique characteristics of students, schools and states, yet still fulfil the curriculum developer's requirements. A disadvantage is that it is incomplete. It lacks a full scope and sequence of lessons, the precise placement of concepts and skills, the selection of topics and learning activities, and the strategies for assessment, management of materials and other practical matters. In a sense, the incomplete nature of a framework is a necessity based on the understanding that curriculum developers and school personnel must make the final adjustments to the curriculum in terms of the unique characteristics of the school, community and students.

In Figure 2, we list some general characteristics that should facilitate the translation of goals to a curriculum framework. The list of characteristics is by no means complete or intended to suggest a particular curriculum. We intend only to provide an orientation or characteristics that individuals can use to develop a curriculum framework. We have found it quite helpful to use this list also to describe the current curriculum, thus creating a discrepancy model for current and proposed science curriculum.

Goals (e.g., learn science knowledge and processes)
Rationale (e.g., social change, scientific advances)
Grade Levels (e.g., K–6, 10–12)
Time Requirements (e.g., 20 Min./Day at K–2; 55 Min./Day at 10–12)
Student Population (e.g., all students, at-risk)
Type of Schools (e.g., urban, rural)
Academic Subjects (e.g., life science, integrated)
Curriculum Emphasis (e.g., STS, fewer topics in greater depth)
Relationship to Other Subjects (e.g., complements health, supports reading)
Curriculum Materials (e.g., textbook, student modules)
Instructional Emphasis (e.g., reading, active learning)
Instructional Strategies (e.g., hands-on, cooperative learning)
Instructional Model (e.g., BSCS 5Es Model, Learning Cycle)
Educational Equipment (e.g., kits, local equipment)
Educational Courseware (e.g., MBL, telecommunications)
Assessment (e.g., built into instruction, portfolios, end-of-unit tests, performance-based)
Implementation (e.g., concerns-based adoption model, staff development)

Figure 2: Some characteristics of a curriculum framework for science

This discussion of the development of curriculum frameworks makes the general and abstract nature of the goals of developing scientific literacy more specific and concrete, thus taking an initial step towards the problem of achieving a common goal and accommodating the unique requirements of different regions or countries.

TRANSFORMING FRAMEWORKS TO SCIENCE CURRICULUM

In this section, we discuss some issues associated with the development of materials for school science programs. Our discussion might be general due to the international audience and the broad range of criteria and constraints that individual science educators must consider. We begin with the premise that transforming criteria described in curriculum frameworks for science programs represents the best efforts of individuals within the constraints of time and budget and the requirements of their countries or regions within their countries.

In some situations, individual science teachers or teams will develop new materials based on their curriculum framework. We only can imagine that these materials can range from single lessons used in rural schools by teachers who have little science background, to complete science programs used in regions or entire countries. The curriculum frameworks should be invaluable resources in the design of science curriculum; that is why we placed significant emphasis on that section. However, when it comes to the actual development of materials, we have several recommendations. First, teams of scientists, science educators, and science teachers should be used to design and develop the materials. Second, individuals who are not associated directly with development should review the materials for accuracy of science content, usability of the materials by science teachers, and alignment of curricular components such as teaching methods and assessment strategies. Third, materials should be field tested. If possible, curriculum developers should include at least one round of field testing and revision during program development.

Some schools, regions or countries will adapt curriculum materials for their unique setting. In the 1960s and 1970s, for example, over 20 different countries adapted materials from the Biological Sciences Curriculum Study (BSCS). Adaptation of science curriculum should include more than translation of the program from one language to another. The curriculum framework can establish the 'closeness of fit' or 'compatibility' of a current science curriculum with the specifications of the school, region, or country. The probability of identifying a program that is perfectly compatible with specifications is quite low, which is the reason for our recommendation to adapt a program. Using similar characteristics and comparing the extant program with the curriculum framework will identify those aspects of the program that require modifications and perhaps additions. Depending on the degree of adaptation, the new curriculum might need review, field testing and evaluation.

TRANSFORMING CLASSROOM PRACTICES

Changing the science curriculum implies changes in teaching science. In fact, consistent with the theme of this chapter, the final translation of a curriculum into actual classroom practices must be considered an essential aspect of any curriculum development effort. Science teachers must make the final decisions about the use of science materials in their classrooms. Of necessity, they will make decisions based on unique aspects of the classroom. Some of those unique aspects include the basic needs of students, students' conceptual levels and developmental stages, available resources, background of the science teacher, time available for instruction, the teacher's understanding of science, and assumptions about students' learning.

We associate terms such as 'implementation' and 'staff development' with this final step of curriculum reform. Based on research (Fullan 1982; Hall & Hord 1987; James & Hord 1988), we recommend that implementation and staff development should be a significant consideration in the development of any science curriculum. We recognise the complicated nature, time, and constraints when considering the diversity of schools and science curricula. But, teachers must understand science content and pedagogy. They should understand the philosophy and materials of the program, and the expected outcomes and assessment strategies of the program. Some of the responsibility for full implementation of a science curriculum belongs to the curriculum developers; the curriculum must be complete, accurate and provide the appropriate resources and support for teachers. Others will have to assume responsibility for administrative support, staff development, and the provision of materials and equipment.

SOME PRINCIPLES FOR DESIGNING AND DEVELOPING SCIENCE CURRICULUM

This section presents some fundamental principles that transcend differences in economic, developmental, political ideology and religious preference. Core ideas about the science curriculum that could facilitate constructive adaptation and cooperative development are identified. These principles are presented from the perspective of science curriculum, but our general view is that they represent a synthesis that incorporates many issues confronting the international community in the reform of science education.

Design and Development of Science Curriculum Should Recognise that Student Learning Neither Begins Nor Ends With the Science Curriculum.

Constructivist literature on learning informs us that students already have conceptions of the natural and designed world and that they have developed explanations for many phenomena. In addition, an individual's science education occurs outside the school and in other settings, such as the family and peer culture, and through other social influences, such as the media and organised religion. Although the form and accuracy of the science education which a student receives from these sources can be questioned, its occurrence and influence cannot be questioned. This suggests the need for recognition of students' current understandings, and the meanings of those understandings for the students, as science programs are designed, developed and implemented.

Design and Development of Science Curriculum Should Include Strategies, Resources and Materials for Science Content, Teaching, Assessment and Implementation.

In the past, science educators primarily have focused on the content and secondarily on instruction, leaving assessment and implementation to others or ignoring them completely. The design and development of science curriculum must incorporate assessment as a part of the curriculum and instruction. The development of science curricula must account for who is going to use the science program, where they are going to use the program, and how they are going to learn about the program. This recommendation places an additional burden on those responsible for new science curriculum, but it provides a complete, coherent and consistent program that actually is used. The burden is a challenge but it is worth the effort.

Design and Development Should Recognise and Incorporate the Human Resources, Especially Science Teachers, in the Transformation of Goals to Practices in Order to Optimise the Classroom Learning Environment and Enhance the Development of the Learner.

Any science curriculum must meet general criteria, such as accurately representing science concepts and methods of inquiry and appropriately accommodating students' learning and development. Curriculum developers have some responsibility to recognise science teachers' needs, such as classroom management and program effectiveness, as it is the science teacher who has to establish the connections between the curriculum and students and use those connections to develop meaning and enhance learning. Development of science curriculum must be done with a sensitivity to the environments and situations in which teachers use the materials and a realisation that any new program probably requires more change for those teaching the program than for those designing and developing the program.

Science teachers have the responsibility to adapt materials for their unique situations, to be clear and to modify their teaching to both new science content and educational approaches. The changes in teaching science suggested in this discussion are likely to result in personal and professional stress among the teachers responsible for implementing the science curriculum. On the part of those developing science programs, we must recognise the changes that will occur and design programs that best meet the science teachers' needs, such as management, effectiveness and efficiency. Others in the educational system must assume responsibility for supporting the implementation process through adequate materials, supplies, equipment, and staff development. We cannot avoid the personal and professional stress associated with change, but we can recognise it and provide adequate support for the science teacher who must assume responsibility for implementing the program.

Design and Development of Science Curricula Should Consider the Culture and Educational Context From Which, and Into Which, One Plans to Implement the Curriculum.

Science educators must strive to maintain the integrity of science, education, and cultural diversity. We can avoid the pitfalls of one region or nation dictating curriculum, even unintentionally. To do this, we must be sensitive to educational needs and requirements and focus on helping the classroom teacher to adapt the curriculum framework to usable materials and adjust current teaching practices so they are more effective. Science education personnel and programs can be thought of as resources. Some nations, regions, territories and schools have more resources than others. The critical issue is not the existence of resources, but the way in which the resources are used, the way in which they are exported and imported, and the way in which they are modified to meet the needs of science teachers.

CONCLUSION

In this chapter, we have attempted to synthesise many excellent ideas from diverse individuals who, over the years, have addressed the general theme of science curriculum. Collectively, they convey a message of hope that we can help students progress towards a goal of scientific literacy. Individually, the work of reforming science programs will take the creativity, insight, knowledge and skills of those who understand the unique requirements of their nations, schools and teachers.

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