1.1 Learning in Science – From Behaviourism Towards Social Constructivism and Beyond

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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.
CONCEPTIONS OF LEARNING

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 preinstructural 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.
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