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Constructing Scientific Knowledge in the Classroom

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The view that knowledge cannot be transmitted but must be constructed by the mental activity of learners underpins contemporary perspectives on science education. This article, which presents a theoretical perspective on teaching and learning science in the social setting of classrooms, is informed by a view of scientific knowledge as socially constructed and by a perspective on the learning of science as knowledge construction involving both individual and social processes. First, we present an overview of the nature of scientific knowledge. We then describe two major traditions in explaining the process of learning science: personal and social constructivism. Finally, we illustrate how both personal and social perspectives on learning, as well as perspectives on the nature of the scientific knowledge to be learned, are necessary in interpreting science learning in formal settings.

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The core commitment of a constructivist position, that knowledge is not transmitted directly from one knower to another, but is actively built up by the learner, is shared by a wide range of different research traditions relating to science education. One tradition focuses on personal construction of meanings and the many informal theories that individuals develop about natural phenomena (Carey, 1985; Carmichael et al., 1990; Pfundt & Duit, 1985) as resulting from learners’ personal interactions with physical events in their daily lives (Piaget, 1970). Learning in classroom settings, from this perspective, is seen to require well-designed practical activities that challenge learners’ prior conceptions encouraging learners to reorganize their personal theories. A different tradition portrays the knowledge-construction process as coming about through learners being enculturated into scientific discourses (e.g., Edwards & Mercer, 1987; Lemke, 1990). Yet others see it as involving apprenticeship into scientific practices (Rogoff & Lave, 1984). Our own work has focused on the study of ways in which school students’ informal knowledge is drawn upon and interacts with the scientific ways of knowing introduced in the classroom (e.g., Johnston & Driver, 1990; Scott, 1993; Scott, Asoko, Driver, & Emberton, 1994). Clearly there is a range of accounts of the processes by which knowledge construction takes place. Some clarification of these distinct perspectives and how they may interrelate appears to be needed.

A further issue that requires clarification among science educators is the relationship being proposed between constructivist views of learning and implications for pedagogy. Indeed, Millar (1989) has argued that particular views of learning do not necessarily entail specific pedagogical practices. Furthermore, the attempts that have been made to articulate “constructivist” approaches to pedagogy in science (Driver & Oldham, 1986; Fensham, Gunstone, & White, 1994; Osborne & Freyberg, 1985) have been criticized on the grounds that such pedagogical practices are founded on an empiricist view of the nature of science itself (Matthews, 1992; Osborne, 1993), an argument that is examined later in the article.

In this article we shall present our view of the interplay among the various factors of personal experience, language, and socialization in the process of learning science in classrooms, and discuss the problematic relationships between scientific knowledge, the learning of science, and pedagogy.

The Nature of Scientific Knowledge

Any account of teaching and learning science needs to consider the nature of the knowledge to be taught. Although recent writings in the field of science studies emphasize that scientific practices cannot be characterized in a simplistic unitary way, that is, there is no single “nature of science” (Millar, Driver, Leach, & Scott, 1993), there are some core commitments associated with scientific practices and knowledge claims that have implications for science education. We argue that it is important in science education to appreciate that scientific knowledge is both symbolic in nature and also socially negotiated. The objects of science are not the phenomena of nature but constructs that are advanced by the scientific community to interpret nature. Hanson (1958) gives an eloquent illustration of the difference between the concepts of science and the phenomena of the world in his account of Galileo’s intellectual struggles to explain free-fall motion. For several years Galileo

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collected measurements of falling objects representing acceleration in terms of an object's change in velocity over a given distance, a formulation that led to complex and inelegant relationships. Once he began to think about acceleration in terms of change of velocity in a given time interval, then the constant acceleration of falling objects became apparent. The notion of acceleration did not emerge in a non-problematic way from observations but was imposed upon them. Scientific knowledge in many domains, whether explanations of the behavior of electrical circuits, energy flow through ecosystems, or rates of chemical reactions, consists of formally specified entities and the relationships posited as existing between them. The point is that, even in relatively simple domains of science, the concepts used to describe and model the domain are not revealed in an obvious way by reading the "book of nature." Rather, they are constructs that have been invented and imposed on phenomena in attempts to interpret and explain them, often as results of considerable intellectual struggles.

Once such knowledge has been constructed and agreed on within the scientific community, it becomes part of the "taken-for-granted" way of seeing things within that community. As a result, the symbolic world of science is now populated with entities such as atoms, electrons, ions, fields and fluxes, genes and chromosomes; it is organized by ideas such as evolution and encompasses procedures of measurement and experiment. These ontological entities, organizing concepts, and associated epistemology and practices of science are unlikely to be discovered by individuals through their own observations of the natural world. Scientific knowledge as public knowledge is constructed and communicated through the culture and social institutions of science.

There are studies in the history and sociology of science that portray the knowledge that emerges as a result of activity within the scientific community as relativist and solely the result of social processes (Collins, 1985; Latour & Woolgar, 1979). Moreover, this relativist position argues that there is no way of knowing whether such knowledge is a "true" reflection of the world, and that the notion of scientific "progress" is therefore problematic. This apparent "irrationalism" and associated relativism of science is currently a matter of dispute in science studies and science education. But a view of scientific knowledge as socially constructed does not logically imply relativism. In proposing a realist ontology, Harré (1986) suggests that scientific knowledge is constrained by how the world is and that scientific progress has an empirical basis, even though it is socially constructed and validated (a position that we find convincing).

Whether or not a relativist perspective is adopted, however, the view of scientific knowledge as socially constructed and validated has important implications for science education. It means that learning science involves being initiated into scientific ways of knowing. Scientific entities and ideas, which are constructed, validated, and communicated through the cultural institutions of science, are unlikely to be discovered by individuals through their own empirical enquiry; learning science thus involves being initiated into the ideas and practices of the scientific community and making these ideas and practices meaningful at an individual level. The role of the science educator is to mediate scientific knowledge for learners, to help them to make personal sense of the ways in which knowledge claims are generated and validated, rather than to organize individual sense-making about the natural world. This perspective on pedagogy, therefore, differs fundamentally from an empiricist perspective.

**Learning Science as an Individual Activity**

Although Piaget did not refer to himself as a "constructivist" until later in his life (Piaget, 1970), the view that knowledge is constructed by the cognizing subject is central to his position. As his statement "l'intelligence organise le monde en s'organisant elle-même" (intelligence organizes the world by organizing itself; 1937, p. 311) reflects, Piaget's central concern was with the process by which humans construct their knowledge of the world. In broad terms, Piaget postulated the existence of cognitive schemes that are formed and develop through the coordination and internalization of a person's actions on objects in the world. These schemes evolve as a result of a process of adaptation to more complex experiences (through the process Piaget called *equilibration*). New schemes thus come into being by modifying old ones. In this way intellectual development is seen as progressive adaptation of individual's cognitive schemes to the physical environment. Piaget acknowledged that social interaction could play a part in promoting cognitive development through, for example, making different viewpoints available to children through discussion. For development to occur, however, equilibration at the individual level is seen as essential.

Although later in life Piaget addressed the relationship between individual knowledge schemes and the history of science (Piaget & Garcia, 1989), and indeed his underlying quest was essentially epistemological, the focus of much of his research program was on how individuals make sense of the physical world through the development of content-independent logical structures and operations. By contrast, the research program into children's scientific reasoning that has emerged over the last 20 years has focused on domain-specific knowledge schemes in the context of children's learning of science. Children's conceptions of physical phenomena have been documented in a wide range of science domains (Carmichael et al., 1990; Driver, Guesne, & Tiberghien 1985; Pfundt & Duit, 1985; West & Pines, 1985). Although this field of research focuses on domain-specific knowledge rather than general reasoning schemes, it shares a number of commonalities with a Piagetian perspective and can lead to similar perspectives on pedagogy. Both view meaning as being made by individuals, and assert that meaning depends on the individual's current knowledge schemes. Learning comes about when those schemes change through the resolution of disequilibrium. Such resolution requires internal mental activity and results in a previous knowledge scheme being modified. Learning is thus seen as involving a process of conceptual change. Teaching approaches in science based on this perspective focus on providing children with physical experiences that induce cognitive conflict and hence encourage learners to develop new knowledge schemes that are better adapted to experience. Practical activities supported by group discussions form the core of such pedagogical practices (see, for example, Nussbaum & Novick, 1982; Rowell & Dawson, 1984). From this personal per-
spective, classrooms are places where individuals are actively engaged with others in attempting to understand and interpret phenomena for themselves, and where social interaction in groups is seen to provide the stimulus of differing perspectives on which individuals can reflect. The teacher’s role is to provide the physical experiences and to encourage reflection. Children’s meanings are listened to and respectfully questioned. In the following passage Duckworth describes clearly the kinds of interventions that are helpful:

What do you mean? How did you do that? Why do you say that? How does that fit in with what she just said? Could you give me an example? How did you figure that? In every case these questions are primarily a way for the interlocutor to try to understand what the other is understanding. Yet in every case, also, they engage the other’s thoughts and take them a step further (1987, pp. 96–97).

The teacher’s activities and interventions are thus portrayed as promoting thought and reflection on the part of the learner with requests for argument and evidence in support of assertions. There is, in our view, a significant omission from this perspective on knowledge construction. Developments in learners’ cognitive structures are seen as coming about through the interaction of these structures with features of an external physical reality, with meaning-making being stimulated by peer interaction. What is not considered in a substantial way is the learners’ interactions with symbolic realities, the cultural tools of science.

Furthermore, in viewing learning as involving the replacement of old knowledge schemes with new, the perspective ignores the possibility of individuals having plural conceptual schemes, each appropriate to specific social settings. (Scientists, after all, understand perfectly well what is meant when they are told “Shut the door and keep the cold out” or “Please feed the plants.”) Rather than successive equilibriums, it is argued that learning may be better characterized by parallel constructions relating to specific contexts (Solomon, 1983). Bachelard’s (1940/1968) notion of “conceptual profile” can be drawn on usefully here. Instead of constructing a unique and powerful idea, individuals are portrayed as having different ways of thinking, that is, a conceptual profile, within specific domains. For example, in everyday life a continuous view of matter is usually adequate in dealing with the properties and behavior of solid substances. Different perspectives can, however, be drawn upon: A quantum view of matter is epistemologically and ontologically different from an atomistic view, and both of these are different from a continuous model. These three perspectives might form an individual’s conceptual profile for solids, and each will be appropriate in different contexts. Thus, a chemist dealing with a synthesis reaction might find it more useful to consider atoms as material particles rather than as a set of mathematical singularities in fields of force (Mortimer, 1993).

Learning Science as the Social Construction of Knowledge

Whereas the individual construction of knowledge perspective places primacy on physical experiences and their role in learning science, a social constructivist perspective recognizes that learning involves being introduced to a symbolic world. This is well expressed in Bruner’s introduction to Vygotsky’s work:

The Vygotskian project [is] to find the manner in which aspirant members of a culture learn from their tutors, the vicars of their culture, how to understand the world. That world is a symbolic world in the sense that it consists of conceptually organized, rule bound belief systems about what exists, about how to get to goals, about what is to be valued. There is no way, none, in which a human being could possibly master that world without the aid and assistance of others for, in fact, that world is others. (Bruner, 1985, p. 32)

From this perspective knowledge and understandings, including scientific understandings, are constructed when individuals engage socially in talk and activity about shared problems or tasks. Making meaning is thus a dialogic process involving persons-in-conversation, and learning is seen as the process by which individuals are introduced to a culture by more skilled members. As this happens they “appropriate” the cultural tools through their involvement in the activities of this culture. A more experienced member of a culture can support a less experienced member by structuring tasks, making it possible for the less experienced person to perform them and to internalize the process, that is, to convert them into tools for conscious control.

There is an important point at issue here for science education. If knowledge construction is seen solely as an individual process, then this is similar to what has traditionally been identified as discovery learning. If, however, learners are to be given access to the knowledge systems of science, the process of knowledge construction must go beyond personal empirical enquiry. Learners need to be given access not only to physical experiences but also to the concepts and models of conventional science. The challenge lies in helping learners to appropriate these models for themselves, to appreciate their domains of applicability and, within such domains, to be able to use them. If teaching is to lead students toward conventional science ideas, then the teacher’s intervention is essential, both to provide appropriate experiential evidence and to make the cultural tools and conventions of the science community available to students. The challenge is one of how to achieve such a process of enculturation successfully in the round of normal classroom life. Furthermore, there are special challenges when the science view that the teacher is presenting is in conflict with learners’ prior knowledge schemes.

Informal Science Ideas and Commonsense Knowledge

Young people have a range of knowledge schemes that are drawn on to interpret the phenomena they encounter in their daily lives. These are strongly supported by personal experience and socialization into a “commonsense” view. Research that has been conducted worldwide has shown that children’s informal science ideas are not completely idiosyncratic; within particular science domains there are commonly occurring informal ways of modeling and interpreting phenomena that are found among children from different countries, languages, and education systems. One of the areas that has been most thoroughly studied is in-
formal reasoning about mechanics. Here there is a commonly held conception that a constant force is necessary to maintain an object in constant motion (Clement, 1982; Gunstone & Watts, 1985; Viennot, 1979). This notion differs from that of Newtonian physics, which associates force with change in motion, that is, acceleration. It is not, however, difficult to understand how experiences such as pushing heavy objects across a floor or pedaling a bicycle can be seen to fit with a “constant force implies a constant force” notion. In another domain, that of reasoning about material substance, children see no problems in considering matter as appearing and disappearing. When a log fire burns down to a pile of ash, children state that matter is “burnt away” (Andersson, 1991). Older children may acknowledge that there are gaseous products from the fire. These, however, are not seen as substantive, but as having different ethereal properties (Meheut, Saltiel, & Tiberghien, 1985). “Gases, after all, cannot have mass or weight; otherwise, why don’t they just fall down?” Indeed, for many young people the idea that air or gas can have weight is most implausible. Many even postulate that they have negative weight in that they tend to make things go upwards (Brook, Driver, & Hind, 1989; Stavy, 1988). A similar form of reasoning is used about the role of gases in biological processes such as photosynthesis, respiration, and decay (Leach, Driver, Scott, & Wood-Robinson, in press).

These are just some examples of the types of informal ideas that are pervasive in the reasoning of young people and adults. In the domains such as the ones referred to here, we argue that there are commonalities in informal ways of reasoning partly because members of a culture have shared ways of referring to and talking about particular phenomena. In addition, the ways in which individuals experience natural phenomena are also constrained by the way the world is.

As far as people’s everyday experiences are concerned, the informal ideas are often perfectly adequate to interpret and guide action. Fires do burn down to result in a small pile of ash—a widely used way of getting rid of unwanted rubbish. If you want to keep a piano moving across the floor you do need to keep up a constant push. It is not surprising that ideas that are used and found useful are then represented in everyday language. Phrases such as being “as light as air” or something being “completely burned up” both reflect and give further support to underlying informal ideas. We argue, therefore, that informal ideas are not simply personal views of the world, but reflect a shared view represented by a shared language. This shared view constitutes a socially constructed “commonsense” way of describing and explaining the world.

During the years of childhood, children’s ideas evolve as a result of experience and socialization into “commonsense” views. For very young children (aged 4–6), air only exists as a wind or a draft—young children do not conceptualize air as a material substance. The notion of air as stuff normally becomes part of children’s models of the world by age 7 or 8. This stuff is then conceptualized as occupying space but as being weightless or even having negative weight or upness (Brook et al., 1989). This example illustrates a much more general point: that the entities, such as air-as-stuff, that are taken as real by children, may be quite different at different ages. In other words, children’s everyday ontological frameworks evolve with experience and language use within a culture. This change corresponds with what others describe as radical restructuring of children’s domain specific conceptions (see Carey, 1985; Vosniadou & Brewer, 1992).

“Commonsense” ways of explaining phenomena, as pictured here, represent knowledge of the world portrayed within everyday culture. They differ from the knowledge of the scientific community in a number of ways. Most obviously, common sense and science differ in the ontological entities they contain: The entities that are taken as real within everyday discourse differ from those of the scientific community. Secondly, common sense reasoning, although it can be complex, also tends to be tacit or without explicit rules. Scientific reasoning, by contrast, is characterized by the explicit formulation of theories that can then be communicated and inspected in the light of evidence. In science, this process involves many scientists in communication with one another. Although tacit knowledge undoubtedly has a place in science, the need for explicitness in theory formulation is central to the scientific endeavor. Thirdly, everyday reasoning is characterized by pragmatism. Ideas are judged in terms of being useful for specific purposes or in specific situations, and, as such, they guide people’s actions. The scientific endeavor, on the other hand, has an additional purpose of constructing a general and coherent picture of the world. The scientific commitment, therefore, is not satisfied by situationally specific models, but strives for models with the greatest generality and scope.

**Learning Science as Involving Individual and Social Processes**

We now consider what we see as the implications of the distinctions between common sense and scientific reasoning for the learning of science. We have argued that learning science is not a matter of simply extending young people’s knowledge of phenomena—a practice perhaps more appropriately called nature study—nor of developing and organizing young people’s commonsense reasoning. It requires more than challenging learners’ prior ideas through discrepant events. Learning science involves young people entering into a different way of thinking about and explaining the natural world, becoming socialized to a greater or lesser extent into the practices of the scientific community with its particular purposes, ways of seeing, and ways of supporting its knowledge claims. Before this can happen, however, individuals must engage in a process of personal construction and meaning making. Characterized in this way, learning science involves both personal and social processes. On the social plane the process involves being introduced to the concepts, symbols, and conventions of the scientific community. Entering into this community of discourse is not something that students discover for themselves any more than they would discover by themselves how to speak Esperanto.

Becoming socialized into the discourse practices of the scientific community does not entail, however, abandoning commonsense reasoning. Human beings take part in multiple parallel communities of discourse, each with its specific practices and purposes. There is considerable interest in the science education community at present in the process of conceptual change. Learning science is being characterized in some quarters as promoting conceptual change from students’ informal ideas to those of the scien-
tific community (Hewson, 1981; Posner, Strike, Hewson, & Gertzog, 1982; West & Pines, 1985). We see a problem in this characterization in that we would not expect students necessarily to abandon their commonsense ideas as a result of science instruction. As argued earlier, students still have such ideas available to them for communication within appropriate social contexts (Solomon, 1983).

Some researchers portray students' learning in science as reflecting similar patterns of change as have occurred in science itself, through progressive restructuring of students' underlying theories (Carey, 1985; Chinn & Brewer, 1993; McCloskey, 1983; Vosniadou & Brewer, 1987). Although we recognize that learning science does involve some restructuring of ideas, we argue that viewing learning as theory change puts too great an emphasis on the theory-like nature of students' informal ideas. We argue that their tacit and situated nature distinguishes them from scientific theories. Furthermore, learning science in school means more than changing from one set of theories to another; it means being consciously articulate about what constitutes theories in the first place.

A social perspective on learning in classrooms recognizes that an important way in which novices are introduced to a community of knowledge is through discourse in the context of relevant tasks. Science classrooms are now being recognized as forming communities that are characterized by distinct discursive practices (Lemke, 1990). By being engaged in those practices, students are socialized into a particular community of knowledge, a process described as a cultural apprenticeship (Rogoff & Lave, 1984; Seeley Brown, Collins, & Duguid, 1989). The discursive practices in science classrooms differ substantially from the practices of scientific argument and enquiry that take place within various communities of professional scientists; this is hardly surprising when one considers the differences between schools and the various institutional settings of science in terms of purposes and power relationships. This disjunction has been recognized, and some science education researchers are experimenting with ways of organizing classrooms so as to reflect particular forms of collaborative enquiry that can support students in gradually mastering some of the norms and practices that are deemed to be characteristic of scientific communities (Eichinger, Anderson, Palincsar, & David, 1991; Roseberry, Warren, & Conant, 1992).

**Learning in the Science Classroom**

In this section we identify some of the discursive practices that support the coconstruction of scientific knowledge by teachers and students and that also reflect features of scientific argumentation. We present brief episodes of teaching and learning in science classrooms and draw upon both personal and social perspectives on learning to interpret what is happening in each case. The examples are taken from studies that we have conducted in collaboration with teachers, in science classrooms in the United Kingdom, in which explicit attention has been given to the differences between students' informal thinking about a particular topic and the science view (Scott, Asoko, & Driver, 1992).

The episodes are not intended to present exemplary instances of teaching and learning. Rather, they have been selected to illustrate the ways in which students develop personal meanings in the social context of the classroom, how scientific meanings are appropriated and how ontological and epistemological differences between informal and science views can create obstacles to personal understanding.

Light rays: Negotiating "new conceptual tools"—new ontological entities

A class of 8-9-year-old pupils was involved in an introductory series of lessons on light (see Asoko, 1993). Children at this age tend to consider light as a source or an effect (Guesne, 1985) but are less likely to conceptualize light as existing in space and traveling out from a source. The teacher, Michael, was interested in helping the class to develop the idea that light travels through space and that it travels in straight lines. Once he had established agreement that light travels in straight lines, he planned to introduce the conventional representation of light "rays."

Initially, Michael invited the class to consider the light in their classroom, which the children all agreed was sunlight. He then explored this notion with them further by asking where the sunlight comes from.

**Pupil 1:** From the Sun.

**Michael:** You mean that the light that's coming through that window has come from the Sun? (several simultaneous replies)

**Pupil 2:** It's from the heat—because it is so hot it makes a bright light.

**Michael:** So how does it get here? If the light is at the Sun, how come it is here as well? Martyn?

**Pupil 3:** 'Cause the Sun's shining on us.

**Michael:** But it is 93 million miles away—so how come the light from the Sun is here on the table?

**Pupil 4:** Is it because of the ozone layer? (There then followed a short exchange in which several pupils contributed ideas about the hole in the ozone layer allowing more sunlight through, after which Michael re-posed the question.)

**Michael:** But how does the sunlight get here?

**Pupil 5:** It travels here.

**Michael:** Coulton says, and his exact words are, that "it travels here." In other words, light moves from the Sun to here...

**Pupil 5:** Yes.

**Michael:** 93 million miles. Is that right?

**Pupils:** Yes (chorus of many voices).

In this interchange, Michael indicated that the Sun "shining" could be further elaborated and, with contributions from the class, focused on the idea of light as something that travels out from the source through space. His interaction with the class as this idea was explored gives an indication that the idea is generally accepted as plausible, an important feature in the coconstruction of classroom knowledge.

The idea that light travels was further developed through a practical activity carried out in groups. Each group of 3-4 children had a set of equipment comprising a 12-volt bulb placed centrally under an octagonal cardboard box about 35 cm in diameter, placed on a large sheet of paper. A slit about 12 cm high and 0.5 cm wide was cut in each of the eight faces. The children were asked to think about what they would see when the bulb was switched on and to draw what they expected to see on the paper. Al-
most all the children drew lines at 90° to the faces extending from the slit to indicate the path of the light. The lines varied in length from 2–3 cm to about 30 cm. When all the children had made at least one prediction, all the lamps were switched on simultaneously in the darkened room. The spectacular effect caused some excitement and not a little surprise when children realized that instead of traveling only a short distance, the beams of light continued across the paper and could be seen, in a vertical plane, when they met a surface such as the wall or a child’s body.

Michael called the class together to discuss their observations. He drew a plan view of the octagonal box on a flip chart. Drawing a line to represent the path of the light, he commented that everyone had made predictions about the position of the line that agreed with what they saw, but commented that many people in the class thought the light would stop.

Michael: Is that right?
Pupil 1: No, it carries on.
Michael: It carries on. How long would it carry on?
Pupil 2: Right to the end. Just keeps carrying on.
Pupil 3: Just keeps carrying on, is that...?
Pupil 4: It can’t stop. You can’t stop light without turning it off.

In this sequence, the notion that light “keeps carrying on” is again interpreted in part of a shared discourse. Michael then invited children to come up and draw more lines on his drawing to show where the light will go. After the children had done this Michael began using the words ray of light to describe the path of light.

In this extended set of sequences, Michael was introducing the children through discourse to the scientific way of seeing, making it plausible to them in the context of a memorable experience. Once he had satisfied himself that the children had a mental representation for “the path the light travels along,” he introduced the convention or symbolic representation of the light ray, a cultural tool that would be used in subsequent lessons. Throughout the sequence, a coherent story evolved, a story that Michael, through feedback, checked was shared by the class. This process of developing shared meaning between teacher and students is at the heart of making what Edwards and Mercer (1987) call common knowledge in the classroom. This common knowledge or shared discourse then referred to a new ontological framework about light, a framework in which light travels, and travels in straight lines (represented symbolically by “light rays”) over long distances.

Air pressure: Scaffolding “a new way of explaining”—conflict between common sense and scientific views

The process by which new ways of explaining are developed by students can involve dialogic interactions between the teacher and individuals, or small groups of students. In these interactions, the adult (or a more competent peer) provides what Bruner (1986) called “scaffolding” for the students’ learning as they construct new meanings for themselves.

In an instructional sequence on air pressure with 11–12-year-old students (Scott, 1993), the teacher had developed, through demonstrations and discourse with the class, a new way of explaining a range of simple phenomena (such as why a plastic bottle collapses inward when air is withdrawn from it). This new way of explaining was based on differences in air pressure inside and outside the bottle, and the class was then asked to work in groups to use the pressure difference idea to explain further phenomena, such as how suction cups hold on to surfaces and how a liquid can be drawn into a teat pipette.

In the following passages, we see examples of an adult “expert” attempting to “scaffold” students’ reasoning in terms of a pressure difference model. We also see the ways in which students’ existing informal theories, such as “vaccum suck,” influence their personal sense making.

Christa and Adele completed an activity with the suction cups and were surprised at the amount of force needed to pull them off a smooth surface. They considered their explanation for this:

Christa: It’s a flat surface and there’s no air in the cup there, so there’s less air in than there is in the outside, so it’ll stick down.
Adult: So what does this pushing...this sticking it down?
Christa: Air.
Adele: Suction.
Adult: What’s suction?
Adele: It’s something that pulls...it’s something that pulls it down...
Adult: A minute or two ago, you said it was something to do with pushing the air out here.
Adele: Yeah.
Adult: And then you also said it was something to do with suction. Are these the same explanations, or are they different?
Adele: They’re nearly...(Adele is not sure and comes to a halt.)

The adult then referred the two girls to the earlier demonstration of the collapsing plastic bottle that they explained in terms of the difference in air pressure inside and out. The girls then returned to consider the case of the suction cups.

Adult: Now, where’s the inside and the outside of this?
Adele: Well...that’s the inside (indicates the underside of the suction cup).
Adult: Yes...right.
Adele: Yeah, and that’s the outside.
Adult: Uh huh—can you use the explanation like the one used for the bottle to explain what happens here? (The adult refers once again back to the collapsing plastic bottle.)
Adele: Has it got anything to do with gravity?
Adult: What makes you say that?
Adele: Pulling it down.

After further exchanges, Adele and the adult agreed that you can have gravity acting even when there is no air, so they are really different things. They continued considering the suction cups:

Adele: It’s sticking to the bottom of there—it [air] all comes out of the sides.
Adult: All right, and what about the air on the outside?
Christa: And the air on the outside’s pushing it down.
Adele: So it’s hard to pull up.
In this extract, the adult structured the course of the reasoning, first reminding the girls of the explanation the class constructed for the collapsing plastic bottle and then supporting the girls in making the link to the case of the suction cup by guiding them to consider the air inside, and the air outside.

Shortly afterwards, Adele raised a further question.

**Adele:** How is it when you put it down and then you pull a little corner up it slips up?

**Adult:** Oh, that’s a very good question. Do you want to think about that for a minute?

**Adele:** It’s, it’s...

**Christa:** No, I’ll show you what it is. It’s the air, it can get back in, can’t it?

**Adele:** Yeah, it’s getting back in, so the air’s pushing it upwards, isn’t it?

**Both:** Yeah!

Here, the adult withdrew support or scaffolding from the girls, except for being an interested audience, and the girls confidently used the pressure difference explanation by themselves. However, a final question from Christa suggests that problems may still exist:

**Adult:** Now... (long pause)... do you have any questions about this?

**Christa:** Why... why does air push it down... when air’s come out of the side? Why does air push it down?

Christa’s question suggests that although she had been successful (with the support of the adult) in constructing the pressure difference explanation in this case, it may still lack plausibility for her (“Why does air push it down?”). In fact, it is highly unlikely that any previous experience or talk about static air would support the idea that it creates such large pressures. The new way of explaining challenges the students’ ideas about what air can and cannot do; it challenges their personal ontologies of air.

The examples presented here draw attention to the fundamental (but frequently overlooked) point that different domains of science involve different kinds of learning. In the first example, the young students appeared to experience little difficulty in understanding and believing that light travels and keeps on traveling unless blocked. They adopted the scientific discourse and used the ideas productively. The situation in the second example appears to be rather different. The teacher had carefully engaged students in activities and discourse to support them in constructing the science view, and yet we see students experiencing real difficulties in making those science models meaningful and appropriating them for themselves. We suggest that these differences in student response can, in part, be accounted for by considering the ontological and epistemological demands of learning in the separate science domains in question. What is common to both cases, however, is the process whereby a teacher, familiar with the scientific way-of-seeing, makes the cultural tools of science available to learners and supports their (re)construction of the ideas through discourse about shared physical events.

**Summary and Final Comments**

The view that scientific knowledge is socially constructed, validated, and communicated is central to this article. We have presented a perspective on science learning as a process of enculturation rather than discovery, arguing that empirical study of the natural world will not reveal scientific knowledge because scientific knowledge is discursive in nature. We have shown that learners of science have everyday representations of the phenomena that science explains. These representations are constructed, communicated, and validated within everyday culture. They evolve as individuals live within a culture. We have shown that there are epistemological and ontological differences between everyday and scientific reasoning. Although learning science involves social interactions, in the sense that the cultural tools of science have to be introduced to learners, we have argued that individuals have to make personal sense of newly introduced ways of viewing the world. If everyday representations of particular natural phenomena are very different from scientific representations, learning may prove difficult. We have argued that the relationship between views of learning and pedagogy is problematic, and that no simple rules for pedagogical practice emerge from a constructivist view of learning. There are, however, important features of the mediation process that can be identified. If students are to adopt scientific ways of knowing, then intervention and negotiation with an authority, usually the teacher, is essential. Here, the critical feature is the nature of the dialogic process. The role of the authority figure has two important components. The first is to introduce new ideas or cultural tools where necessary and to provide the support and guidance for students to make sense of these for themselves. The other is to listen and diagnose the ways in which the instructional activities are being interpreted to inform further action. Teaching from this perspective is thus also a learning process for the teacher. Learning science in the classroom involves children entering a new community of discourse, a new culture; the teacher is the often hard-pressed tour guide mediating between children’s everyday world and the world of science.

What is presented here differs fundamentally from the positivist program in education with its emphasis on technical rationality and a nonproblematic portrayal of the knowledge to be acquired. By participating in the discursive activities of science lessons, learners are socialized into the ways of knowing and practices of school science. This presents a major challenge for educators: The challenge lies in fostering a critical perspective on scientific culture among students. To develop such a perspective, students will need to be aware of the varied purposes of scientific knowledge, its limitations, and the bases on which its claims are made. A crucial challenge for classroom life is therefore to make these epistemological features an explicit focus of discourse and hence to socialize learners into a critical perspective on science as a way of knowing.

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