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LEARNING AND TEACHING "SCIENTIFIC CONCEPTS": VYGOTSKY'S IDEAS REVISITED

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In his chapter in Thinking and Speech on the development of scientific concepts, Vygotsky (1987, chap.6, hereafter DSC) initiated a discussion of an issue that continues to be of fundamental importance for education, namely that of the relationship between the development of what might be called decontextualized, formal thinking and school instruction. However, despite the insightful and many-faceted nature of his exploration of this issue, I shall argue that the account he offers needs to be significantly enriched, first by setting it in the context of his other theoretical writings and, second, by expanding it to take account of more recent developments in the relevant fields.{1}

My argument will be divided into two parts. In the first, I shall adopt a semiotic perspective, examining the relationships among activity, concepts, thinking, and various modes of speech. In the second part of the paper, I shall consider scientific concepts from the perspective of the instructional activities which are intended to provide opportunities for students to appropriate the mode of thinking with which they are associated. In both cases I shall argue that, on both the sociohistorical and the ontogenetic planes, a full account of development must recognize the key mediating role played by the semiotic tool of written language.

The relationship between scientific and spontaneous concepts

Vygotsky's discussion of the development of scientific concepts is carried out quite largely in terms of the ways in which they differ from everyday, or spontaneous, concepts, both in their defining characteristics and in their manner of acquisition. Compared with spontaneous concepts, he argues, scientific concepts have four features which the former lack: generality, systemic organization, conscious awareness and voluntary control. Of these four features it is the first two that are criterial in labelling a concept `scientific'; what distinguishes this category of concepts is not so much the fields to which they apply as the way in which - whatever the field - they relate to experienced `reality'. Whereas everyday concepts are related to the world of experience in a direct but relatively ad hoc manner, scientific concepts are both more abstract and more general; their primary relationship is to other concepts within the relevant system and only indirectly to the particular objects and events that they subsume.

While the first two features serve to define the way in which scientific concepts differ from everyday concepts, the second two features, by contrast, are better seen as more general characteristics of a stage of mental development that is associated with, and perhaps dependent on, their acquisition. For this reason, although the two sets of features are different in scope, they are also interdependent. As Vygotsky puts it: "only within a system can the concept acquire conscious awareness and a voluntary nature. Conscious awareness and the presence of a system are synonyms when we are speaking of concepts" (DSC, p.191).

Scientific concepts also differ from everyday concepts in the manner in which they are acquired. Unlike everyday concepts, which Vygotsky suggests are appropriated spontaneously by the child through the social interaction that occurs in the course of engagement in jointly undertaken activities in his or her immediate community, scientific concepts can only be acquired as a result of deliberate and systematic instruction in an educational setting. "The development of scientific concepts begins with the verbal definition," Vygotsky asserts (DSC, p. 168). Furthermore, since "the development of concepts and the development of word meanings are one and the same process" (p.180), it is by focusing on the systematic relationships between word meanings that instruction brings the semantic aspect of speech to conscious awareness. And this, in turn, enables the child to make the transition to a higher level of thinking.

Vygotky's interest in the development of scientific concepts can be seen, therefore, as part of his more general concern to explain the development of what he called the higher mental functions and, in particular, of decontextualized thinking. And his reason for making them the focus of attention was that, in so doing, he was able to bring together two important strands in the development of his overall theory: the relationship between speech and thinking and that between instruction and development. This is clearly brought out in the opening paragraphs of the chapter.

> The development of the scientific .. concept, a phenomenon that occurs as part of the educational process, constitutes a unique form of systematic cooperation between the teacher and the child. The maturation of the child's higher mental functions occurs in this cooperative process, that is, it occurs through the adult's assistance and participation. In the domain of interest to us, this is expressed in the growth of the relativeness of causal thinking and in the development of a certain degree of voluntary control in scientific thinking. This element of voluntary control is a product of the instructional process itself. (DSC, pp.168-9, original emphases)

Occurring, as it does, in the opening pages of the chapter, this extract serves as a form of summary of what is to follow and, although much of importance in the chapter is inevitably omitted, I believe it fairly represents the central argument.{2} However, to those who are familiar with Vygotsky's writings more generally, the account it offers of the development of "the higher mental functions", of the role of speech in this process and of the relationship between the social and the individual dimensions of development, is less than satisfactory as a statement of Vygotsky's seminal contribution to our understanding of these issues. In particular, with its focus on the relatively autonomous conceptual development of the individual child, what is missing is an emphasis on the cultural-historical origins of the higher mental functions and on the role of semiotic mediation in their development.

Elsewhere in his writings this theme is given much greater prominence. Indeed, in introducing the following formulation of this central principle, he characterizes it as "the general genetic law of cultural development":

> Any function in the child's cultural development appears twice or on two planes ... It appears first between people as an intermental category, and then within the child as an intramental category. This is equally true of voluntary attention, logical memory, the formation of concepts, and the development of will. (1960 pp.197-8, quoted in Minick, 1987, p.21){3} (emphasis added)

When the development of scientific concepts is treated in accordance with this principle (as the underlined phrase in the quotation suggests it should be), it is clear that an adequate explanation must account for the sociohistorical origins of the intramental functions that these concepts mediate as well as for the transformation of the child's thinking that results from their appropriation. How such an account might be developed is suggested elsewhere in Vygotsky's writings and, over the intervening years, his suggestions have been extended and complemented by work in a variety of intellectual disciplines. In what follows, I shall draw on both these sources to sketch one form that a more complete explanation of the development of scientific concepts might take on both the sociohistorical and ontogenetic planes of development.

Intellectual Development through Appropriation of Semiotic Tools

Central to Vygotsky's `genetic' approach to the explanation of both sociohistorical and individual development is the recognition of the pivotal role of tools. Their mediating function is clearly apparent in the case of physical activity and, indeed, cultural history can be written very largely in terms of the technological developments that the invention of new material tools has made possible. However, even more important for human development is the mediating role performed by semiotic tools, or signs, of which the most powerful and versatile is language. For, in joint activity of all kinds, speech (i.e. the use of spoken or written language as tool) performs two crucial functions: first, it enables the participants to coordinate their actions in relation to the object in view and, second, it provides a means for representing and reflecting on the persons, things and actions involved and on the relationships between them. However, like other tools, language also changes over time. For when speech is used to mediate the solution of novel problems, the cultural meaning potential of the language system itself is modified and developed to meet the new demands that are placed on it (Halliday, 1978; Wells, 1994a).

But speech has yet a further function in a sociocultural account of development, in that it provides one of the principal means whereby the knowledge and practices constructed in the past can be transmitted to future generations. Much more is involved than a simple transfer of information, however. For, as both Vygotsky (1981) and Halliday (1975, 1993b) make clear, in mastering the culture's linguistic resources and the functions they serve, through participation in interaction in the context of joint activity, the novice both transforms his or her potential for social action and also constructs for him or herself the means for performing these functions intramentally in the medium that Vygotsky called "inner speech". Thus, in the speech through which more and less expert participants negotiate and comment on their joint activity, the sociohistorical and the ontogenetic planes of development are brought into a productive interaction with each other, each being influenced by, and influencing, the other (Cole, 1985).

This account of the sociocultural basis of the higher psychological functions in tool-mediated joint activity is clearly expressed in the following extract from Leont'ev's summary of Vygotsky's initial insight:

> The tool mediates activity and thus connects humans not only with the world of objects but also with other people. Because of this, humans' mental processes (their "higher psychological functions") acquire a structure necessarily tied to the sociohistorically formed means and methods transmitted to them by others in the process of cooperative labor and social interaction. But it is impossible to transmit the means and methods needed to carry out a process in any way other than an external form - in the form of an action or external speech. In other words, higher psychological processes unique to humans can be acquired only through interaction with others, that is, through interpsychological processes that only later will begin to be carried out independently by the individual. (Leont'ev, 1981, pp.55-6) (emphasis in the original)

If we now bring this perspective to bear on what Vygotsky has to say in the chapter from Thinking and Speech about the development of scientific concepts, and about their relationship to the spontaneous concepts that the child constructs through his or her everyday experience, we shall see that the account offered there needs to be modified in a number of ways.

First, it must be emphasized that all concepts, both spontaneous as well as scientific, are appropriated from the culture in the course of specific forms of intermental activity. As studies of children's language development have shown (Bruner, 1983; Halliday, 1975; Wells, 1985), the meaning potential that the informal registers of the culture's language provides as a tool for thinking and communicating with is appropriated and mastered by the child in the course of innumerable conversations with family members in the context of a wide variety of everyday activities. While the adult's or older peer's contributions to these interactions may rarely have a deliberate instructional purpose, the child's learning of the everyday concepts that are encoded in the spoken texts that they jointly construct is as much dependent on `instruction in the zone of proximal development' as is the learning of the scientific concepts encountered in school (Rogoff & Wertsch, 1984; Wells, 1986, 1990). Indeed, Vygotsky himself makes the same point in his other major formulation of the role of the ZPD (Vygotsky, 1978, chap.6).

However, although both spontaneous and scientific concepts are tied to specific activities and discourse genres (Bakhtin, 1986), there is a significant difference between the two types of concept in their origins and characteristic situations of use. While spontaneous concepts are learned in the course of participation in the activities in which they are typically used, this is less likely to be the case with scientific concepts. Since the latter have arisen and are typically used in activities which are characterized by an explicitness, reflexivity and formulability that is not functional in everyday practice, they are most effectively learned in specialized settings, such as schools and, as Vygotsky suggested, they probably require some form of systematic instruction.

Second, it must equally be emphasized that, not only are all concepts appropriated from the culture, but the conceptual resources available for appropriation vary from one culture to another as a result of the particular conditions encountered in their different trajectories of historical development. As Luria puts it, expressing this sociohistorical variability, consciousness is "not given in advance, unchanging and passive, but shaped by activity and used by human beings to orient themselves to their environment, not only in adapting to conditions but in restructuring them" (1976, p.8, quoted in Ratner, 1991, p.70). In particular, the extent to which a culture develops systems of concepts that are highly abstract and decontextualized depends upon the complexity and diversity of the activities in which its members engage, and upon the requirement for formal, theoretical thinking that these activities entail.

From this it follows that the development of scientific concepts may not be the universal culmination of intellectual development that Vygotsky's account would seem to suggest. Rather, the extent to which children develop systemically organized concepts of a high degree of generality depends, first, upon the widespread need within the culture for such a semiotic resource to mediate the construction of socially organized technical knowledge and, second, on the existence of an institutional framework within which successive generations can undertake the necessary apprenticeship. The fact that `scientific rationality' has come to be highly valued in Western cultures does not therefore mean that it is superior, in some absolute sense, to other modes of thinking; rather, its preeminence in these cultures is a function of the particular historical trajectory that they have taken (Tulviste, 1986 (quoted in Wertsch, 1991; Wertsch, 1994). Indeed, despite conflicting interpretations of the results of particular studies, this conclusion seems to be generally supported by recent comparisons of cognitive development in markedly different cultural contexts (Bruner, 1972 ; Ratner, 1991; Scribner & Cole, 1981). Only where both the above intermental conditions are met - as they are in contemporary industrialized societies - do children develop the generalized propensity for decontextualized thinking that is the outcome of the individual intramental developmental process that is emphasized in Vygotsky's (1987) account of the development of scientific concepts.

Moreover, even in these societies, the extent to which individuals acquire this propensity depends very much on the actual opportunities they have to participate in activities in which this mode of thinking is jointly enacted (Wells, 1981).

Now if, as I have just argued, scientific concepts are most likely to emerge in a culture with a complex division of labor and a formal system of education, the next step is to identify the semiotic practices and artifacts that have enabled this sociohistorical development to occur. In the following section, I shall propose that it is writing and, more specifically, expository writing that, in conjunction with other semiotic artifacts and practices, has performed this mediating role.

Writing as Tool and as Artifact

As a means for mediating intellectual activity, the crucial characteristic of writing is that it gives a permanent representation to meaning. Written texts can be reread, silently or aloud, and - either by the writer or by subsequent readers - they can be discussed and revised, with each successive version of the text providing the basis for further reflection and reformulation. Thus, as Olson puts it: "What literacy contributes to thought is that it turns the thoughts themselves into worthy objects of contemplation" (1994, p.277).

It is this function of written language that Vygotsky emphasized in his discussion, in DSC, of the consequences for the individual of learning to read and write. Instruction in written speech and grammar, he argued, enables the child to make a transition in his thinking "from an unconscious, automatic plane to a voluntary, intentional and conscious plane" (DSC, p. 206). Thus, by appropriating this cultural tool for reflective thinking, the learner brings under conscious and deliberate control meaning-making capacities that he or she has, until that time, only deployed spontaneously in oral speech.

In DSC, Vygotsky focused on the role of written speech in the intramental development of individual members of cultures that were already highly literate. However, just as important is the part this powerful tool has played in the historical development of those same cultures through its role in the mediation of intermental activity.

To understand in more detail just how this historical development has taken place, it is useful to make explicit a key difference between oral and written speech which results from the permanence of written text: namely, that it allows a separation to be made between writing as process and writing as product - between the activity of composing and the text that is composed. In the activity of composing, the resources of written language are used as a tool to mediate both communication and the thinking that is necessarily involved; the written text that results from the composing process, on the other hand, is an artifact - both a physical object and a fixed representation of the meanings that are made. But, because this artifact continues to exist beyond the point of utterance, it may become, in its turn, a tool to be used in further processes of knowledge construction and dissemination. This distinction between process and product - between tool and artifact - is particularly important, I believe, for an understanding of the role that writing has played in the development of the kind of decontextualized thinking that is associated with scientific concepts.

First, let us consider the process. As with other tools, it is through being used in novel situations and for new purposes that the tool of writing has been developed over the centuries. This applies both to the physical conventions of layout, punctuation, and so on, and to the development of differentiated registers and genre forms, each conventionally organized to serve a particular kind of purpose. At the same time, these progressive refinements of the tool have made possible new functions that were formerly difficult, if not impossible, to perform in the mode of oral speech. Thus, from being used, initially, mainly to record information for accounting and tax purposes, writing has come to play a key role in almost all aspects of life and particularly in the processes of knowledge construction and dissemination (Halliday, 1993a; Ong, 1982).

In these latter domains, this two-way relationship between form and function in the process of writing has played a particularly important role. For, as numerous scholars have attested, it is when their thinking is mediated by the tool of writing that they are best able to develop their ideas. As they exploit the affordances and constraints of their language's available meaning potential, they struggle to formulate their thoughts in a coherent and communicable form and, in the process, sometimes create meanings that had not previously existed, thus transforming both the culture's knowledge and the tool that mediates its production.

On the other hand, when we take the perspective of the products that result from the process of writing, it is clear that written texts have made an equally important and complementary contribution to the cumulative construction of knowledge. As artifacts that have a relatively permanent existence, they make it possible for scholars far removed in time, and even in cultural tradition, to take over, utilize and transform the ideas of their predecessors in solving contemporary problems and, in turn, to leave in the texts they create a permanent record of their activity. In this "progressive discourse" (Bereiter, 1994), which is ongoing over long periods of time, written texts function as both tools and artifacts.

It is thus easy to see how systematized bodies of knowledge are gradually constructed, refined and extended in activities that are mediated by writing. Less obvious is the fact that concepts, too, may be socially constructed in the transformation of the written medium that occurs over time as it is used as tool in the course of these activities. And nowhere is the result of this transformation more apparent than in the proliferation of abstract scientific concepts that characterizes the various written genres by means of which so much of the activity of science is carried out.

From one point of view, the high frequency occurrence of technical and abstract terms in these scientific texts may seem hardly surprising, since it is a major goal of scientific activity to formulate abstract, general principles and theories concerning the entities and relationships hypothesized to underlie material, social and psychological phenomena. Indeed, some might see the abstractness of the language of the text as no more than the expression of abstract conceptual categories and relations that preexisted their linguistic representation. However, what I want to suggest is that it may be more appropriate to see the scientific concepts that are verbally represented in these genres of text as semiotic artifacts that, at some point in time, were brought into existence in the very act of composition.

Such is the position adopted by Halliday who, in a recent series of papers (Halliday, 1988, 1993a; Halliday & Martin, 1993) has traced the historical development of scientific written English. In them, he shows how, from the writings of Chaucer in the late fourteenth century, this use of language has evolved over the intervening centuries, both molded by the need to communicate about observations and experiments in the physical sciences and mediating the development of the new form of specialized knowledge that both directed and resulted from these activities. He further shows how this mode of language use has subsequently been appropriated by other fields of scientific inquiry and also by institutions of government, industry and commerce, so that it now characterizes almost all formal written transactions.

Probably the most important characteristic of this generalized register, as it occurs today, is the use of what Halliday calls `grammatical metaphor', that is to say, the linguistic realization of material processes and attributes as nouns or noun phrases When nominalized in this way, processes can be treated as `things', which can be modified or defined within their respective noun phrases; they can then be related to further nominalized processes within a single clause, with the verbal element expressing the relationship between them. The result of this and other related changes that have been introduced into scientific written English is "a discourse that moves forward by logical and coherent steps, each building on what has gone before" (Halliday, 1988, p.172).

The use of grammatical metaphor to represent processes as abstract nouns (the typical form in which `scientific' concepts are encoded) did not start with Chaucer, of course, for it is already found in written texts from much earlier periods. However, as Halliday demonstrates with respect to English, there is no doubt that this feature of expository prose has been developed and extended as an integral part of the rise of science and technology in modern culture. In other words, the existence of many`scientific' concepts in their characteristic linguistic realization as nominalized verbs of process is an outcome of the way in which the grammar of written language has evolved to serve the demands of scientific and technical activity.

The form this historical progression has taken can be illustrated by means of the following set of sentences, adapted from an example cited by Berkenkotter (1994):

1. The water in the ground here is flowing to the east.
2. Ground water flows in an easterly direction.
3. Ground water flow is in an easterly direction.

In these three sentences, which can be seen as representing points along a continuum from informal everyday speech to formal scientific writing, there is a parallel progression, from specific and concrete to general and abstract, in the concepts realized in the subject noun phrases: "the water (in the ground here)" → "ground water" → "ground water flow".

From the point of view of the development of higher mental functions, however, what is most significant about this historical development is that, with these changes in the tool of written language that scientists use to represent what they do and understand, have gone changes in their ways of making sense of that which is represented. As Wartofsky (1979) puts it:

> ... our own perceptual and cognitive understanding of the world is in large part shaped and changed by the representational artifacts we ourselves create. We are, in effect, the products of our own activity, in this way; we transform our own perceptual and cognitive modes, our ways of seeing and of understanding, by means of the representations we make. (p.xxiii)

So, the forging of the tool of scientific prose has brought into existence new forms of linguistic expression and, with them, new ways of categorizing (i.e. constructing similarities) between experienced phenomena.

Learning Scientific Concepts through Appropriating Scientific Written Genres

So far, in explaining the role of written language in the development of what Halliday calls the synoptic perspective on experience, I have focused on the plane of sociohistorical development. However, this synoptic way of seeing and understanding is not limited to those who are at the forefront of scientific endeavor. It is available, in principle, to anyone who masters the register by means of which this way of seeing is represented, through using it as a tool in some activity in which it is relevant. In other words, learning to construe experience in terms of the synoptic mode can occur through, and as a consequence of, engaging in educational activities in which the synoptic perspective is emphasized through the use of genres of language which are organized in terms of the written grammar.

Here is how Halliday explains it:

> A written text is itself a static object: it is language to be processed synoptically. Hence it projects a synoptic perspective on to reality: it tells us to view experience like a text, so to speak. In this way writing changed the analogy between language and other domains of experience; it foregrounded the synoptic aspect, reality as object, rather than the dynamic aspect, reality as process, as the spoken language does...
>
> In a written culture, in which education is part of life,

> children learn to construe their experience in two complementary modes, the dynamic mode of the everyday commonsense grammar and the synoptic mode of the elaborated written grammar. (1993, p.111-112)

As will be clear from the preceding discussion, there is more than a coincidental similarity between the distinction Halliday is drawing between the dynamic and synoptic modes of construing experience through language and the distinction Vygotsky makes between everyday and scientific concepts. And as both would agree, what is involved is the construction of a new form of knowledge through a new mode of language use - learning that typically takes place in school.

However, there is a third comparable distinction to be found in recent theorizing and that is the distinction that is made by Bruner (1986) between the two modes of thought that he refers to as `narrative' and `paradigmatic'. As he points out, the narrative mode is primary and it underlies children's early experience of conversation. It is a discourse of doings and happenings, of actions and intentions: agents act in the light of prevailing circumstances in order to achieve their goals. This is clearly the dynamic perspective on experience to which Halliday refers and the basis on which Vygotsky's spontaneous concepts are constructed. It is a mode of discourse in which the grammatical organization of the clause corresponds to the `natural' relationship between the entities, actions and circumstances in terms of which we typically describe and explain behavior, our own and other people's.

By contrast, Bruner suggests, the paradigmatic mode "attempts to fulfill the ideal of a formal, mathematical system of description and explanation" (1986, p.12). Synoptic in its orientation, it provides a way of symbolically managing the complexity and variability of experience, allowing it to be reconstrued in abstract categories, which can be systematically related in taxonomies; instances can then be counted, and made amenable to operations of mathematics and logic. The relationship between Bruner's paradigmatic mode of thought and the thinking that is brought into being through the deployment of scientific concepts is clearly apparent. Providing the means of realization for both, I would suggest, is the synoptic mode of language use that is characteristic of the written scientific genres that children first encounter in school.

Although these three theorists have different reasons for drawing the distinctions that they do, the parallelisms between them are striking. Indeed, I would suggest that it is essentially the same distinction in each case. It can be summarized as follows. In early childhood, children learn to construe the world of their experience in terms of the spontaneous concepts that are realized in the dynamic, narrative modes of spoken language that occur in everyday acivities in the life of the family and local community. By contrast, the development of scientific concepts occurs chiefly in the course of educational activities that emphasize reflexive and metarepresentational thinking and takes place in later childhood through the gradual appropriation and mastery of the genres of written discourse, which have themselve evolved over time to mediate the social construction of scientific knowledge.

At this point, then, it may be enlightening to compare the present proposal with the account put forward by Vygotsky in DSC. Significantly, that chapter does contain a substantial section on learning to write. And, in section 4 on instruction, Vygotsky states that "instruction in writing is among the most important subjects in the child's early school career .. it elicits the development of functions that have not yet matured" (p.211). However, his analysis of learning to write is almost entirely limited to a discussion of the conscious awareness and voluntary control of mental processes that is necessarily involved. There is no recognition of the role of writing as a cultural tool that is used in scientific activity, neither is there any connection made between scientific concepts, seen as word meanings, and the written texts in which they are used to explain and debate the phenomena that are investigated in the activity of `doing science'.

Several reasons can be suggested for what, from a contemporary sociocultural perspective, appear to be quite serious limitations in Vygotsky's account. The first is the state of knowledge about semantics at the time when he was writing, which is reflected in his choice of unit of analysis (Wertsch, 1985). Word meaning certainly has the advantage, as he claimed, of belonging "not only to the domain of thought but [also] to the domain of speech" (Vygotsky, 1987, p.47). However, as Halliday and other linguists have more recently made clear, meaning is not confined to lexical items in isolation, but is realized in texts constructed in particular situations through interrelated choices from all the linguistic systems simultaneously (Halliday, 1978; Lyons, 1981). In order to understand the development of the child's `meaning potential', therefore - including the development of scientific concepts - it is necessary to study the development of the child's grammar as a whole, since it is in the reconstruction of the grammar that is required of him in learning to read and write that the child is gradually led to reconstrue his or her experience in the synoptic/paradigmatic mode.

Second is the discursive context in which Vygotsky's account of the development of scientific concepts was written. Like several other chapters in Thinking and Speech, DSC advances Vygotsky's own ideas through a critical, dialogic engagement with the writings of other contemporary theorists. In this case, the target was Piaget's proposed explanation of the child's intellectual development and, in particular, the discontinuity, in his account, between the child's spontaneous and "non- spontaneous" concepts (DSC, p.174). Although the point of Vygotsky's critique was to show the critical role of instruction in the child's construction of scientific concepts, the dominant perspective throughout the chapter is the one provided by Piaget, which is thoroughly individualistic in orientation. Preoccupied with clarifying the nature of development on the plane of intramental activity, Vygotsky was led to a relative neglect of the equally important plane of intermental activity, which is where the contribution of instruction is made.

In the second part of this paper, therefore, I shall turn to a consideration of what Vygotsky had to say about the part played by instruction in the development of scientific concepts.

Towards a Pedagogy of Participation in Practice

As Vygotsky states in the opening paragraphs of DSC, one of the main concerns motivating his empirical study of the development of scientific concepts was "the more general problem of the relationship between instruction and development" (p.167). In contrast to the appropriation of everyday concepts, which he believed took place spontaneously in the course of naturally occurring activities in the home and community, scientific concepts could only be mastered with the aid of instruction, which, in his view, is both systematic and teacher-directed. However, as already noted, there is an element of self-contradiction here, since we know from Vygotsky's other writings that he believed that all semiotic tools are mastered in the course of joint activities with the assistance of other members of the culture. It seems, therefore, that in using the term "instruction" here he must have meant something different from such spontaneous assistance.

What exactly he had in mind is suggested, in general terms, in his discussion of the role of instruction in relation to the zone of proximal development: "Instruction is only useful when it moves ahead of development" (DSC, p.212) That is to say, instruction that contributes to learning is always pitched in advance of what the child can manage alone, leading him "to carry out activities that force him to rise above himself" (p.213). What this might mean, in practice, is described in the context of explaining how children came to be able to successfully complete the test sentences containing material from the social sciences that were used in his experiment with Shif. This success, he suggests, is the outcome of a long process of instruction, in which: "The teacher, working with the school child on a given question, explains, informs, inquires, corrects, and forces the child himself to explain. All this work on concepts, the entire process of their formation, is worked out by the child in collaboration with the adult in instruction" (DSC, pp.215-6).

In this description of the dialogic strategies a teacher might use, we certainly recognize one important component of instruction, particularly in a setting where the teacher is interacting with an individual student, or a small group, in relation to a task in which they are jointly engaged. As I have argued elsewhere (Wells, 1996), this form of responsive but challenging follow-up to a student's performance not only enables the student to make progress in bringing the current task to a satisfactory conclusion, but it also enacts ways of making meaning which the student can appropriate and deploy him- or herself on future occasions.

No doubt this form of dialogue occurred quite frequently in the "clinical discussions" which, in Vygotsky's empirical research, supplemented the sentence-completion tasks involving social science and everyday material. Indeed, as Scardamalia and Bereiter (1983) have argued, coinvestigations between student and researcher not only yield evidence of a student's understanding of the task, but they also provide an occasion for the student to learn through reflecting on that understanding and, with the assistance of the researcher, to perform at a level that he or she would be unable to attain alone.

Vygotsky may also have seen instances of such dialogue in the lessons he and his colleagues observed during their research since, as he notes, these lessons were "specially organized for this purpose" (DSC, pp.167-168).

Nevertheless, any suggestion that this form of dialogue is the principal means through which students learn scientific concepts would be totally implausible. For, given the number of students in a typical class, both in Vygotsky's time and today, such constructive ways of following up on an individual student's performance can occur only quite rarely for any particular student and, for many students, they hardly occur at all.

However, a more serious problem with this characterization of school instruction is its failure to consider how such occasions of dialogic assistance are related to the activity settings in which they might arise (Tharp & Gallimore, 1988). In fact, Vygotsky himself does not seem to have devoted much attention in his writings to the larger issue of institutionalized schooling or to the issues concerned with curriculum planning and enactment. However, we can get a fairly good idea of what he might have written by extrapolating from the summary of his ideas by Leont'ev that was quoted above (p.).

As I suggested there, several key features of Vygotsky's overall theory are identified in this quotation. These include the centrality of joint activity for both sociohistorical and ontogenetic development, the mastery of cultural practices as the means for the development of the higher mental functions, and the mediating role of semiotic tools in both these processes (Sinha, 1989). And although Vygotsky does not discuss them in DSC, all are relevant, I believe, for an understanding of the role of instruction in the development of the mode of thinking that is mediated by scientific concepts.

In recent years, a variety of attempts has been made to develop forms of pedagogy that are in accordance with these and similar principles. For example, building on Dewey's (1938) emphasis on learning through doing and on constructivist ideas derived from Piaget's work, there has been a considerable increase in programs, particularly in the elementary years, which seek to root school learning in students' practical, `hands-on' experience (Duckworth, 1987). More recently, there has also been a greater emphasis on the importance of cooperation in learning (Sharan & Sharan, 1992). Both these developments can be clearly seen in the work of the Science 5-13 program in Britain in the 1970s and 80s, in Itakura's hypothesis-experiment-instruction method in Japan (Hatano & Inagaki, 1991) and in a number of current initiatives in the teaching of science and mathematics in North America. There has also been a growing awareness of the essential role of language, both spoken and written, and in dialogue with self as well as with others, as the means whereby students attempt to bring their existing knowledge to make sense of new experience and information. This is seen in the work of Barnes (1976) and Britton et al. (1975) in Britain and in the spread of the `whole language' movement in North America and Australia (Goodman and Goodman, 1990; Harste et al., 1984; Cambourne, 1988). In many of these developments, Vygotsky's ideas have been explicitly or implicitly drawn on.{4}

From these, and other reports to be mentioned below, a concensus is beginning to emerge about some of the key features that would be expected in any approach to curriculum and instruction that seeks to enact the principles of sociocultural theory. Together, they make for a form of pedagogy that I have elsewhere referred to as constituting a "semiotic apprenticeship" (Wells, 1994b).

Schooling as Semiotic Apprenticeship

The metaphor of apprenticeship has been employed quite widely in recent discussions of the learning and teaching relationship (Collins et al., 1989; Rogoff, 1990) and it has much to recommend it. First, it emphasizes the purposeful, productive nature of the activities through which learning occurs and their relevance to the life of society as a whole. Knowledge is acquired in and for action and not simply for show; the criterion of success is not the reproduction of information in response to questions on a test but the ability to use what has been learned to find effective solutions to problems encountered in situations beyond the classroom.

Second, with its roots in traditional craft practices, this metaphor draws attention to the fact that it is through learning to use the tools that have been developed over time to mediate the achievement of the goals of particular activities that knowledge is transmitted from the past and appropriated and further developed by each new generation. It also highlights the social origin of individual knowledge and skill, as these are mastered through the learner's participation in more, and more challenging, aspects of the joint activity. At the same time, it must be emphasized that there is more to apprenticeship than simply reproducing the achievements of the past. For the ultimate object must be that the apprentice should become an independent master craftsmen, who creates new artifacts and adds to the cultural resources of skill and knowledge. Transformation of society as well as of the individual learner is therefore an intrinsic aspect of this conceptualization of schooling.

The third advantage of thinking of learning in these terms is that it recognizes the complexity of real-life activities and of the need for collaboration between participants with different kinds and levels of expertise (Rogoff, 1994). This is particularly relevant in our post- industrial society, where relatively mindless, repetitive assembly-line work is being replaced by the need for adaptability and creativity in dealing with the novel problems that regularly arise in knowledge-based activities. It is equally relevant within the classroom where, as a result of policies of destreaming and integration, differences between students in interests and values, as well as in levels of performance and preferred learning styles, reflect the increasing diversity of the communities that they serve.

All these features are given prominence by Lave and Wenger's (1991) characterization of learning as increasingly full participation in communities of practice, a characterization that they derived from the study of a variety of types of actual apprenticeship. But whereas all the examples they observed involved adults learning as an integral aspect of participation in `real-life' practical situations, the learning of scientific concepts has traditionally taken place in the setting of the sequestered classroom. Here, learning is typically treated as an individual accomplishment, and instruction as the transmission from expert to novice of knowledge which, as Lave and Wenger put it, "can be decontextualized ... [from] the communities in which the knowledge that schools are meant to `impart' is located" (1991, pp.40-41). As Engestrom (1991) also points out, the division of labor and the rules and conventions which govern classroom activity systems tend to subvert the goal of developing understanding of the curriculum topic, that is to say the constructing of knowledge that issues in effective action, and to substitute in its place goals more concerned with students' attainment of acceptable grades and the maintenance of unchallenged control by the teacher.

For these reasons, some have argued for the abolition of formal schooling altogether, seeking to replace it by learning through various forms of workplace apprenticeship. However, as well as being impractical for pre-adolescent students, such a proposal would lose the undoubted advantages of an arrangement that allows for learning activities to be organized and paced to meet the needs of the learners rather than being governed by the economic demands of the workplace. It would also forego the opportunity that occurs in the institution of schooling for engagement in the metarepresentational activity of constructing the systemic relationships among concepts and for systematic attention to be given to the development of the disposition for reflexive thinking more generally. That these advantages have too often in the past been bought at the price of curriculum and instruction organized in terms of the delivery of prepackaged chunks of decontextualized information, of rote learning and the economy of test scores, does not mean that no other kind of instruction is possible. The question that has to be resolved, therefore, is not whether systematic instruction is desirable, but what form this instruction should take.

One possibility, that I have documented elsewhere (Wells, 1994b, 1996; Wells & Chang-Wells, 1992), retains many of the critical characteristics of an apprenticeship mode of learning and teaching while placing the emphasis on the creation of a classroom community of inquiry. This is frequently operationalized through engagement with broad themes that are selected in relation to real-world problems and in the light of student interests as well as of externally mandated curriculum guidelines, within which students are encouraged to work, usually in groups, on questions and topics that they find personally relevant and challenging. Under these conditions, ways can be found to create authentic learning opportunities that meet the criteria discussed above. An important feature of this approach is that activities are inquiry-oriented, leading to practical outcomes, and instruction is responsive to the emergent demands of the situation in ways that, over the theme unit as a whole, build towards a systematic understanding of the relevant discipline-based knowledge and to increased mastery of the semiotic tools involved. Approaches of a similar kind have been described by Brown and Campione (1994), Lampert (1992), Roseberry et al. (1992), and Scardamalia and Bereiter (1992).

In such classrooms, written texts play a key role, both as a source of information in relation to the projects in which the students are engaged and as a means of representing the understanding gained so that it can be shared with others. Writing is also used to note results in tables and log-books and to reflect on and speculate about what is being discovered, in journal entries and other informal genres. In all these texts, scientific concepts are being mastered through being used as tools for thinking and problem solving, in ways comparable to those through which they were and are being developed by those who engage professionally in scientific and technological research.

However, it is not only in writing that students grapple with these new concepts. For both action and written texts are surrounded and interpenetrated by small group and whole class discussion, in which these new meanings are co-constructed in relation to what the students already know and can do, both individually and as a result of shared classroom experiences.

The following extract is taken from one such class discussion, which occurred immediately following an activity in which groups of ten and eleven-year-olds had experimented with a number of objects, such as knives, cotton reels, paper and so on, to discover which would complete a simple electrical circuit. The results of this experiment had been recorded in a chart in two columns, headed "bulb lights up" and "bulb does not light up". Now the teacher asks them to draw some conclusions that involve reconstruing the particular findings of the individual trials in the more abstract synoptic categories of `conductors' and `non-conductors' of electricity.

T: Now, just from this chart, what does it tell you?
Is something like paper a good conductor of electricity?

(Several children shake their heads)

So what are the materials that are poor conductors of electricity -
that do not conduct electricity - where electricity cannot pass
through there to get you a complete circuit?
Can you name them? Marie?

M: Cotton reels

T: So what is it made of? Name the material .. did you observe?
What's the cotton reel made of?

A: Plastic

T: Plastic . so plastic's not a good conductor, you see .
What other materials?

E: Um . beer bungs and . wood (almost inaudible)

T: Listen to the question . I want you to make a knowledge
transformation, OK? I want you to transform what you did .
I asked what MATERIALS are not good conductors . I didn't
ask about the beer bung

E: Wood

T: Wood, plastic . What else are not good conductors?

P: Paper

T: Now these are NON-CONDUCTORS (writing the word above the column in the table for `bulb does not light up')
Now can you name for me the CONDUCTORS of electricity - the materials not the objects?

(from Wells, 1994b)

In this example, it is the table, as a genre of written text, that serves to focus the double reconstruing of experience that is required: from the dynamic account of the specific objects tested to the more abstract representation in terms of materials, and then from the everyday categories of materials to the synoptic categories of conductors or non-conductors of electricity. And in this case, the teacher makes the process explicit by talking about the `knowledge transformation' that the students need to make as they learn to use these new scientific concepts.

Later in the morning, the students were, as usual, given time to write in their journals about what they had been doing and learning. This personal writing gave them an opportunity to try using some of the features of the new synoptic genres they were encountering, including such concepts as `conductor' and `non-conductor'. However, as the teacher pointed out (Chang-Wells, personal communication), their journal entries and the other texts they later produced for public display served another important instructional purpose. For, by reading what they had written, the teacher was able to gain a good idea of the sense individual students were making of these new concepts and this, in turn, enabled her to respond to them with guidance and assistance that was appropriately pitched within their individual zones of proximal development.

Returning, then, to the collaborative dialogue that Vygotsky described in DSC, we can see now how it fits into the activity system as a whole. As Vygotsky claimed, it is indeed important; however, it is not the only mode in which learning occurs. Instead, its role is essentially one of mediation, of building bridges between children's spontaneous knowledge, expressed in the dynamic mode of action and the everyday speech in which that action is planned, directed and reported, and the more formal, schooled knowledge which is expressed in the synoptic mode of written language (Lemke, 1990). In this teacher-guided instructional process, scientific concepts are co-constructed as artifacts to represent features recognized to be common across particular objects and events, and then used as tools in the attempt to make further connections.

Conclusion

In recent years, two criticisms have been levelled against Vygotsky's theory of school instruction: first, that it is more concerned with cultural transmission than it is with cultural renewal and the encouragement of innovation and diversity; and, second, that, in its emphasis on the immediate context of interpersonal interaction, it ignores the larger cultural and historical context of the activity systems and ideologies, both local and societal, within which this interaction occurs. To these might be added a third: that the learning of school knowledge, and specifically the development of scientific concepts, tends to be treated as an end in itself rather than as the appropriation and futher development of a set of tools that is used for problem solving in the achievement of goals that the students find personally significant.

As has already been suggested, all these criticisms have some force when considering the characterization of learning and instruction presented in DSC. However, they can all be at least partially countered by returning to the core postulates of his theory, which, I would argue, provide the basis for a more culture-sensitive and transformative conception of schooling. To this end, I have tried in this paper to show how, by drawing on a wider range of Vygotsky's writings and by incorporating the work of some of his successors, it is possible to construct an account of the development of scientific concepts that is both more comprehensive than that which was presented in DSC and more closely attuned to contemporary classroom instructional practices that take their inspiration from his work.

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Notes

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2. I have deliberately omitted the reference in the above quotation to the "earlier maturation of scientific concepts" as compared with everyday concepts, as this is both contentious and only tangentially relevant to the argument I wish to develop.

3. I have quoted from Minick's translation (1987, p.21) rather than from Wertsch's (1981) translation in order to emphasize the `mental' nature of the activities (see Minick's footnote 4).

4. A rather different development of Vygotsky's ideas is to be found in Davydov's pedagogical approach, but this is, as yet, barely known about in the west.