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Constructivism, Education, Science, and Technology

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Abstract

Abstract: The purpose of this paper is to present a brief review of the various streams of constructivism in studies of education, society, science and technology. It is intended to present a number of answers to the question (what really is constructivism?) in the context of various disciplines from the humanities and the sciences (both natural and social). In particular the discussion will focus on four varieties of constructivism: philosophical, cybernetic, educational, and sociological constructivism.

Résumé: Cet article a pour objectif de passer brièvement en revue les différents courants de constructivisme dans les études sur l'éducation, la société, la science et la technologie. Il a également pour intention d'offrir un certain nombre de réponses à la question « Qu'est-ce réellement que le constructivisme ? » dans le contexte de diverses disciplines appartenant aux lettres et sciences humaines, ainsi qu'aux sciences (naturelles et sociales). La discussion se centrera tout particulièrement sur quatre variantes du constructivisme: philosophique, cybernétique, éducatif et sociologique.

Introduction

It is generally acknowledged that constructivism constitutes a very important, although often contested, practical and theoretical perspective in current education research.[1] A first `*mild*' (or ` . *trivial*') version of constructivism[2] originating in the work of Piaget holds that knowledge is actively constructed by the learner and not passively transmitted by the educator. In addition, there is the *radical constructivism* of von Glasersfeld (1990), in which cognition is considered adaptive in the sense that it is based on and constantly modified by a learner's experience.[3] Beyond that, there is the *social constructivist* version of Vygotsky, who in an effort to challenge Piaget's ideas developed a fully cultural psychology stressing the primary role of communication and social life in meaning formation and cognition. The latter version of constructivism is accentuated by theories of sociology of scientific knowledge (SSK), which argue that all knowledge is a social construct in the frame of science and technology studies.

The purpose of this paper is to present a brief review of the various streams of constructivism in studies of education, society, science and technology. In the aftermath of the "science wars" (Gross & Levitt, 1994; Gross, Levitt & Lewis, 1996; Levitt, 1999) and the escalation of the bitter attacks between combatants from on or the other of what C.P. Snow (1959) once called the "two cultures" provoked by the ambiguous "Sokal hoax" (Lingua Franca, 2000), a sober discussion about constructivism is absolutely needed. Before examining why people are so often excited about constructivism (Hacking, 1999), it would be helpful first to clarify what constructivism really is. In this paper we intend to present a number of answers given to the latter question in the context of various disciplines from the humanities and the sciences (both natural and social). Apparently, getting to grips with constructivism would not only contribute to a mitigation of the misunderstandings between inflamed combatants but it could also contribute to the development of an educational best practice on the very understanding of reality, given the sensitive role that education plays in the reproduction of society (Bourdieu & Passeron, 1977).

In particular, our purpose here is to discuss the following four varieties of constructivism: philosophical, cybernetic, educational, and sociological constructivism. The perspective of*philosophical constructivism* , encompassing all the common epistemological presuppositions underlying the other kinds of constructivism, supports the social construction of all-human knowledge and beliefs. Backed up by the cybernetic advances in biology, neurophysiology, and cognition, *cybernetic constructivism* substantiates the basic prospect of philosophical constructivism as a self-referential process of maintaining identity. *Educational constructivism* , which is also labeled as *psychological constructivism* (Phillips, 1995), divides into personal and social constructivism, according to whether it is the individual person or a group who does the constructing or the processing of cognitive and memory structures. The main part of the theories of Piaget and von Glasersfeld fall into the former division, while the theories of Vygotsky into the latter. *Sociological constructivism* , which is called also*social constructivism* with the risk of being confused with the Vygotskian approach, is concerned with the public bodies of knowledge, the various disciplines of science and technology, and how they are socially constructed and interpreted in terms of changing social conditions and interests.

The fact is that constructivism carries a major influence in contemporary science education, although it has been the subject of a heated debate. Remarkably, one of the most important implications of radical constructivism challenges the processes by which individual students actively construct their own knowledge. For example, Cobb et al. suggest that more attention has to be given to the interpersonal or social aspects of learning, i.e., to what appear to be "at least temporary states of intersubjectivity" (Cobb, Wood & Yackel, 1991). Proceeding further, Cobb (1990) calls for constructivist mathematics educators to develop a new "mathematico-anthropological context" in order to refine and apply their ideas to mathematics classroom environments. Moreover, there are plenty of more conventional calls to adopt constructivism as for example in the nineteen-chapter book, *The Practice of Constructivism in Science Education*, published by the American Association for the Advancement of Science, in the Preface of which it is claimed that constructivism represents a `paradigm change' in science education (Tobin, 1993).

Philosophy and Constructivism

Although many would disagree with the constructivist approach, few would silence the psychological influence on education brought about by the constructivist view of learning. In fact it is as "a psychological theory about how beliefs are developed" (Matthews, 1998, p. 2, in his introductory remarks), where the original core of constructivism might be found. However even in this learning core a particular philosophy intervenes or, better said, a particular epistemology[4] is involved.

On the other side, a certain tradition of both old and more recent philosophical theories has generated the conceptual body of that which could be termed *philosophical constructivism*. These views argue that our beliefs and perceptions of the world are purely human constructs, i.e., an active construction rather than a passive reception of sense data. In this way, philosophical constructivism falls into the camp of philosophical anti-realism and hence it could be considered an alternative to objectivism. Common sense realism and scientific realism maintain the existence of a human-independent world, including unobservable entities, which is represented to our perceptions either through direct `correspondence' relations between reality and language or through ubiquitous scientific discoveries. Philosophical constructivists, as anti-realists, deny seeing reality in itself and disregard any claims that we can know anything beyond action and experience. Therefore, they declare that it is we who construct (not discover) the known world on the basis of our experiences and active processes of developing knowledge.

The roots of philosophical constructivism, going back to Aristotle and the ancient Greek instrumentalist philosophy, could be found in Kant's philosophy and Berkeley's philosophy of science. However, various theorists who have effectively reconceptualized the role of observations as theory-laden and subjective in contrast to the traditional approaches of realism and logical empiricism recently brought this perspective to the awareness of a wider public. Among a large number of such authors in post-realist and post-positivist philosophy, we will consider just two of them, Kuhn and Rorty, as they perfectly represent the constructivist view.

Thomas Kuhn's *Structure of Scientific Revolutions* (1962) provides a theory of scientific development, in which `anomalies' and `crises' in the established research tradition necessitate the acceptance of a new ` . *paradigm*'[5] to be extended by the practices of the so prevailing normal science. But this, Kuhn argues, is a truly revolutionary act because of the incommensurability of standards between the old and the new paradigm. Therefore, scientists need to construct, not to discover, "what is really there" by means of persuasion and social justification in order to arrive at a sort of consensus around the emerging new research tradition. Therefore, according to Kuhn, (scientific) reality is understood as a community-generated and community-maintained linguistic-symbolic entity, which paradigmatically constitutes the communities of knowledgeable peers generating them.

The philosopher Richard Rorty has vigorously contested the traditional realist views about the nature of knowledge and adopted an anti-representationalist constructivist view. In his book *Philosophy and the Mirror of Nature* (1979) he tried to deconstruct the dominant metaphor in modern post-Cartesian western philosophy of the human mind as a "Mirror of Nature." According to this metaphor, the human mind is equipped with two working elements, a `mirror,' reflecting reality, and an `inner eye,' contemplating and comprehending that reflection. In the realist tradition, the captured reflection together with the accompanied contemplation constitutes the processes of learning and of the acquisition of knowledge. Rorty, based on the work of Wittgenstein, Heidegger, and Dewey, attacks these metaphysical abstractions of an irreducible outer reality separated from an irreducible inner intellect. His pragmatist thesis (shared by constructivism) is that "we understand knowledge when we understand the social justification of belief, and thus have no need to view it as accuracy of representation" (Rorty, 1979, p. 170).

Cybernetic Constructivism

Second order _ mode 2 - cybernetics (von Foerster, 1984) or cybernetics of self-organization presents another kind of constructivism, which is called *cybernetic constructivism*. This is based on the concept of *autopoiesis* (self-formation) which was formulated by the Chilean cell-biologists Humberto Maturana and Francisco Varela (1980, 1987): An autopoietic system is "organized (defined as a unity) as a network of processes of production (transformation and destruction) of components that produces the components which: (i) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it ... as a concrete unity in space which they (the components) exist by specifying the topological domain of its realization as such a network" (Maturana & Varela, 1980, p. 78-79).

In other words, autopoietic systems are self-contained and self-referential unities, which are qualified as such whenever the following six criteria are satisfied:

1. The system is identifiable through its border.
2. It is analyzable through its components.
3. The interaction of the components obeys the general physical laws (i.e., it is a natural system).
4. The boundary is self-maintained by preferential neighborhood relations (i.e., the system can stabilize its own boundary).

5. The system is contained within and producing the boundary.
6. It is a self-productive system using only its own components or transformed imported material (Mingers, 1995).

Although autopoiesis has originally developed to describe biological cells, subsequently it has been applied to a variety of disciplines covering physical, cognitive, and psychic systems (Maturana & Varela, 1987; Mingers, 1995). Particularly interesting is Luhmann's application of autopoiesis in social, communication, and legal systems (Luhmann, 1989, 1990, 1995).

The constructivist character of autopoiesis is manifested at the level of the closure of the nervous system implying that action and cognition depend on each other without any outside system of reference. According to von Foerster, "my nervous system does not, indeed, cannot, tell me what is `out there,' not because of mechanical but because of logico-semantic reasons. My nervous system cannot tell me anything because it is `me': I am the activity of my nervous system, all my nervous system talks about is its own state of sensory-motor activity" (von Foerster, 1993). In fact, von Foerster (1984) argues that all sensory receptors (i.e., visual, auditory, tactual, etc.) send physically indistinguishable `responses' to the cortex and that, therefore, the `sensory modalities' can be distinguished only by keeping track of the part of the body from which the responses come, and not on the basis of `environmental features.' From this observation von Glasersfeld concludes that "contemporary neurophysiological models may be compatible with a constructivist theory of knowing but can in no way be integrated with the notion of transduction of `information' from the environment that any realist epistemology demands" (von Glasersfeld, 1989).

Piaget and Developmental Psychology

Jean Piaget (1896-1980) is considered to be one of the most influential thinkers in the twentieth century developmental psychology. His approach was based on an evolutionary epistemology analogizing the development of mind to a biological point of view and, so, highlighting the adaptive function of cognition. Von Glasersfeld ranks Piaget in constructivism because "knowledge for Piaget is never (and can never be) a `representation' of the real world. Instead it is the collection of conceptual structures that turn out to be adopted" or, as von Glasersfeld would say, "*viable* within the knowing subject's range of experience" (von Glasersfeld, 1989, p. 126).

For Piaget (1952, 1969) the development of human intellect proceeds through *adaptation*and *organization*. Adaptation is a process of *assimilation* and *accommodation*, where, on the one hand, external events are assimilated into thoughts and, on the other, new and unusual mental structures are accommodated into the mental environment. The process of organization refers to the structuring of the adapted mental material. Piaget considers that the organization of the mind is accomplished through a series of increasingly complex and integrated ways, of which the simplest one is the scheme, i.e., a mental representation of some action that can be performed on an object. For example, actions like sucking, grasping and looking are some of the schemes of an infant. As Piaget identifies knowledge with action, he considers that mental development organizes these schemes in more complex and integrated ways to produce the adult mind.

Piaget assumes that there exist four major periods of development in the evolution of human mind: (a) the sensorimotor period, (b) the pre-operational period, (c) the concrete-operational period, and (d) the formal-operational.

In the sensorimotor period, from birth to two, the child explores the world through action. In this period, first, goal-directed behaviors begin to appear, whereas later on the child can act pretendedly, an indication of internal imaging and manipulation of events. The end of this period occurs with the acquisition of basic language, and the communication of volition through speech.

The pre-operational period is subdivided into the pre-conceptual and the intuitive stages. The pre-conceptual child (age 2 to 4) has . *neither* fully developed concepts *nor* the ability to abstract and discriminate relevant features. The child cannot appropriately use inductive and deductive ways of thinking. The intuitive child (age 4 to 7) forms ideas just from impressions and the child cannot consider more than one variable at once.

In the concrete-operational period (7 to 11 years) the child can manipulate numbers, develop concept formation skills and think hypothetically about coordinated action, where two or more variables can be considered at once.

At the formal-operational period (adolescence and adulthood) the child starts to use abstract reason. Abstract hypotheses can be built along with the capability to hold some variables constant while manipulating a particular variable to determine its influence.

Von Glasersfeld'S Radical Constructivism

Ernst von Glasersfeld is one of the leading advocates of a radical version of constructivism both as a theory of knowledge and as a guide for science education. Asked about the differences in the various versions of constructivism he said: "A few years ago when the term *constructivism* became fashionable and was adopted by people who had no intention of changing their epistemological orientation, I introduced the term trivial constructivism. My intent was to distinguish this fashion from the `radical' movement that broke with the tradition of cognitive representation" (von Glasersfeld, 1992, p. 170).

The radical constructivist movement abandons the traditional philosophical position of realism according to which knowledge has to be a representation of an essential reality, i.e., an `out there' world prior to having been experienced. On the contrary, it adopts the relativist position that knowledge is something, which is personally constructed by individuals in an active way, as they try to give meaning to socially, accepted and shared notions. As von Glasersfeld himself says "knowledge is the result of an individual subject's constructive activity, not a commodity that somehow resides outside the knower and can be conveyed or instilled by diligent perception or linguistic communication" (1990, p. 37).

According to von Glasersfeld (1990, p. 37), all good teachers know that guidance which they give to students "necessarily remains tentative and cannot ever approach absolute determination," because in constructivism there is always more than one solution to a problem and different solutions might be approached from different perspectives.

All these imply that knowledge cannot simply be transferred by means of words. Von Glasersfeld holds: "Verbally explaining a problem does not lead to understanding, unless the concepts the listener has associated with the linguistic components of the explanation are compatible with those the explainer has in mind. Hence it is essential that the teacher have an adequate model of the conceptual network within which the student assimilates what he or she is being told. Without such a model as basis, teaching is likely to remain a hit-or-miss affair. From the constructivist perspective, `learning' is the product of self-organization" (1989, p. 136).

Von Glasersfeld cites the eighteenth century Italian philosopher Giambattista Vico as a significant precursor of constructivism by saying: "One of Vico's basic ideas was that epistemic agents can *know* nothing but the cognitive structures they themselves have put together. He expressed this in many ways, and the most striking is perhaps: `*God is the artificer of Nature, man the god of artifacts*.' Over and over he stresses that `to know' means *to know how to make*. He substantiates this by saying that one knows a thing only when one can tell what components it consists of. Consequently, God alone can know the*real* world, because He knows how and what He has created it. In contrast, the human knower can know only what the human knower has constructed" (1989, p. 123).

As Robert Davis has remarked, anyone "who observes mathematics education has to be impressed by the quite sudden eruption of `constructivism' as a central concern of so many researchers" (Davis, 1990, p. 114). However, overall constructivism has had limited success, with only peripheral impact on the theory and practice of scientific education, although undoubtedly it has given a challenge to reflect on a relativist approach to the teaching and learning processes. Some of these reflections were rather critical against it (Matthews, 1993; Phillips, 1995; Osborne, 1996; Suchting, 1992) and some have urged caution in its adoption (Millar, 1989; Solomon, 1994).

Vygotsky and Social Psychology

Lev Vygotsky (1896-1934), along with Jean Piaget, is considered to be a leading contemporary in developmental psychology. His main works are the posthumous *Thought and Language* (1986) and *Mind in Society* (1978). Vygotsky's main relevance to constructivism derives from his theories about language, thought, and their mediation by society (Bruffee, 1983). He holds the anti-realist position that learning could not be based on a direct association but that the process of knowing is rather a disjunctive one involving the agency of other people and mediated by community and culture. He sees collaborative action to be shaped in childhood when the convergence of speech and practical activity occurs and entails the instrumental use of social speech. Although in adulthood social speech is internalized (it becomes thought), Vygotsky contends, it still preserves its intrinsic collaborative character.

An important part of Vygotsky's work (1986) was critical upon Piaget's contributions in the field. Although they share some common ideas, there exist significant differences between them. On the topic of stages of development, Piaget believed that development precedes learning, while Vygotsky believed the opposite. In particular, on the development of speech, Piaget argues that the egocentric speech of children goes away with maturity, when it is transformed into social speech. On the contrary, for Vygotsky the child's mind is inherently social in nature and so speech moves from communicative social to inner egocentric. Therefore, since the development of thought follows that of speech, Vygotsky claims that thought develops from society to the individual and not the other way.

On the topic of internalization (i.e., the process by which external actions are transformed into internal functions), Vygotsky and Piaget agree on the definition, but they actually start from different points. For Vygotsky, the content of internalization consists of internalized, social, interpersonal relationships and this is why children tend to use the same form of behavior in relation to them as others have expressed toward them. In the process of internalization he believed that egocentric speech constituted just a transitional step leading to the development of inner speech, corresponding to reasoning skills crucial to planning and problem-solving.

Verbal mediation is another crucial issue in the Vygotskian theory. Inevitably, children become recipients of a variety of adults' generalizations and mature conceptualizations, which can even be alternative or opposing. At the process of internalization of these types of speech, the child automatically experiences a silent dialectic in the effort to find solutions or to take decisions. Stressing the role of social interaction, Vygotsky asserted the significance of dialogue as a tool through which individuals collectively, or individually, could negotiate conceptual change.

In his experiments Vygotsky studied the difference between the child's reasoning when working independently contrasted with when working with an adult. He devised the notion of the "*Zone of Proximal Development* " to reflect on the potential of this difference. Through this notion he reached to the concept of a learning environment consisting not only of children and learning material and processes, but children, learning material and interactive communication.[6]

Vygotsky's findings suggest learning environments should involve guided interaction, permitting children to reflect on inconsistency and to change their conceptions not only through Piaget's intelligent action but also through speech and communication. The children's verbal and conceptual maturation can be achieved by exposure to increasingly more expert vocabularies through social interaction.

Observing the behavior of children in experiments of grouping-sorting objects, Vygotsky studied the developmental stages in the formation of conscious behavior and he concluded that children pass through four stages of conceptual development. During the first stage, relationships are developed between the child and the environment. This is the syncretic grouping stage in which the child groups things seemingly at random. It is the formation of chain concepts, "complex formation," that occurs in the second stage, in which the child makes recognizable collections of groups of objects. What follows is the pseudo-concept formation: the child picks the right attributes without being able to explain why, because the concept has actually been learned by rote and not yet by an abstraction of any general rule. Finally, in the fourth stage abstract concepts are formed just like in adults: the child manages to focus on at least one attribute accurately and be able to explain the type of the chosen grouping by naming the attribute.

In a sense these observed stages of concept formation are similar to Piaget's theory, although there are also important differences between them. In fact, Vygotsky held that no rigid maturational progress existed through these stages. Furthermore, Vygotsky emphasized the role of the tutor in the development of these stages. In addition, after having observed the child's interaction, Vygotsky suggested that verbal labels were easily acquired independently of the formation of the corresponding true concepts.

Vygotsky held that thought development is determined by language. In this way he postulated a delicate relationship between thought and language, although he admitted that they have different genetic roots and rates of development. The source of thought is in the biological development of the child, while the source of language is in the social environment. There are definite stages that children pass through in order to develop their thought: a first primitive stage is followed by a later advanced one. In the first stage children may think in complexes of the associative type or concrete groupings of objects connected by facts. During the second phase of advanced thinking, true concepts begin to be formed with increasing fluency. However, in this stage the elementary forms are not abandoned. It is at this stage when humans are capable of vacillating between complexes and concepts. Although complexes are restricted to their elements, advanced concepts fuse and merge with the objects of which they are made, constituting something, which is more than the sum of its parts.

A Brief Guide to Science and Technology Studies

Significant changes in the nature of modern societies are being brought about by the recent developments in communication, information, and biological technologies. To understand the transformation in the structure and context of modern society and culture shaped by the mediation of science and technology requires escaping the conventional approaches stressing an instrumental and value-neutral character of technology. Such is the approach of technological determinism, in which technology is portrayed as an autonomous development driving society towards economic and social progress.

The perspectives of the projects of science and technology studies (STS) give a different understanding of the ways in which the articulations among science, technology, and society constitute the modern contexts of social and cultural realities. In general, these are diverse programs with aims of analyzing the socioeconomic and political factors shaping scientific and technological enterprises, as they become dominant forms of knowledge and practice in modern culture.[7] At the heart of these approaches is the methodology of `*social constructivism* ,'[8] holding that the traces of science and technology on society can only be gauged through human interpretation. In this sense, the context of technology is considered to be essentially social and it is conceived as a construction rather a reflection of the intrinsic properties of technology. The roots of this methodology lie in the *sociology of scientific knowledge* (SSK) (e.g., Bloor, 1976; Collins, 1985; Woolgar, 1988) but, as the methods of social constructivism, starting from science studies, were applied to technology studies, they were diverted in a variety of rather disparate areas.

A first social constructivist approach in technology studies[9] is what is called *strong social constructivism*, an approach strictly derived from the sociology of scientific knowledge and arguing for the socially constructed character of scientific knowledge. It includes the theory of the so-called *social construction of technology* (SCOT) (e.g., Bijker *et al*., 1987) together with the work of H.M. Collins and Steve Woolgar and, in particular, with what Grint and Woolgar (1997) call `anti-essentialism.' According to the strong social constructivist approach, technological change is a genuine social construction to be explained solely by social practices, which have produced its stabilization, as through processes of interpretation, negotiation, and closure, by different social actors.

Under the label of *mild social constructivism* some more moderate approaches are characterized, as the approach of the `*social shaping of technology*' (e.g., MacKenzie, 1991; MacKenzie and Wajcman, 1985). Although these approaches still accept that social factors shape technology, some elements of relative autonomy are recognized to technology. They accept the action of nonsocial factors in technological change and attribute inherent properties and effects to technology, albeit these properties and effects are usually defined in a particular social context and are due to social or political biases embodied by technology.

A third influential approach is that of the `*actor-network theory* ' (ANT) (e.g., Callon, 1986; Latour, 1987). It tries to explain the development and stabilization of scientific and technological objects as they result from the construction of heterogeneous networks, which are concrete alignments between human actors, natural phenomena, and social or technical aspects. In the processes of stabilization of technology, all actors (or `actants') in the network, either human/natural or social/technical, are analyzed through the same impartial prism and the same terms and methods are symmetrically applied to different entities. However, special preference is given to the explanatory role of social elements, such as social groups and interpretation processes.

Although the various social constructivist approaches vary in their perspectives, they possess certain common features. Contrary to the views of technological determinism, social constructivism incorporates contingency and flexibility in the processes of technological change, conceived to take place in a network of heterogeneous factors pertinent to both technology and society under the presence of certain structural natural constraints. In this sense, technological change cannot be analyzed independently of human interpretation; neither can it be attributed to an imagined intrinsic logic of technology. Rather, technological change is shaped in a general common framework involving different acting individuals, social groups, and other relevant technosocial aspects, as they engage in strategies to overcome the existing controversies and oppositions.

Moreover, social constructivism typically maintains the validity of a *principle of methodological symmetry* or *relativism* (Pinch and Bijker, 1987). This principle proclaims a sort of `agnosticism' in the analysis of technological development, as it remains impartial in front of the various scientific controversies and it is reluctant to evaluate any of the knowledge claims made by different social groups about the essence of technology. It was in the sociology of knowledge (Bloor, 1976), where this principle was first formulated, motivated by the idea that in a sociological analysis of knowledge claims both true and false statements can be equally well explained by reference to sociological factors.

A final common element in all social constructivist approaches is the idea that science and technology systems are regulated according to flexible technosocial arrangements by processes of *stabilization* around concrete developments. In fact, as the stabilization of a technology inscribes the way technology functions in society, the stabilization of an artifact results from processes of settling controversies and negotiations among different social groups, which thus arrive at a similar interpretation. In this way, technology is claimed to possess *interpretive flexibility* , as far as it is void of any objective, fixed properties, but allows for different interpretations by relevant social groups. The outcome of technological stabilization through negotiation and social action sometimes is described as the *closure* of the technological development around certain social arrangements.

The social constructivist approaches do offer some interesting advantages, the most worthy of which lies in their detailed empirical analyses and case studies of technological innovation. However, they have also been strongly criticized and they have aroused serious controversy about their effectiveness. In 1991 Langdon Winner had formulated some of the main criticisms against social constructivist technology studies (Winner, 1993). In summary, Winner's criticism refers to the following points:

1. Disregard for the social consequences of technical choice.
2. Exclusion of `irrelevant' social groups.
3. Oversight of cultural issues and social origins of technical choice (in particular, rejection of the notion of `autonomous technology').
4. Lack and apparent disdain for evaluative stances and repudiation of moral or political principles. Nevertheless, one should remark that in the past seven years, there are recent contributions modifying the contents of social constructivism in the light of Winner's criticisms.[10]

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Endnotes

1. Constructivism is not the only insight from psychology brought to science education by the so-called "cognitive revolution" in psychology of the 1960s. Another movement of the modern information-processing approach to cognition is the theory of situated learning (advocated by J. Lave [1988] among others), according to which learning is considered to be a function of the activity, context and culture in which it occurs, i.e., it is situated. In this point of view, situated learning emphasizes that knowledge is maintained in the external social world in contrast to the constructivist claim (at least in its "trivial" version) of the primacy of the individual's internal state in the meaning construction process.

2. Almost all mathematicians today, at least implicitly, adopt the Piagetian constructivist scheme.

3. A recent development of constructivism, called constructionism, derives from the work

of Seymour Papert (1991, 1993) in relation to the use of computers in education. While constructivism regards the subject as an active builder of knowledge, constructionism places a critical emphasis on particular constructions of the subject that are external and shared.

4. That any decent learning theory involves epistemological considerations has been already recognized by Piaget, who called his own research program `Genetic Epistemology' and one of his most influential books was titled Psychology and Epistemology: Towards a Theory of Knowledge (Piaget, 1972).

5. Although the `paradigm' is a fundamental notion in Kuhn's theory, it has been used in different ways. Often by a `paradigm' Kuhn simply means an `exemplar,' an exemplary solution to a specific problem; such a solution could be used as a model to solve other problems in the same field. However there is a more global sense of `paradigm' that Kuhn speaks of, that of a comprehensive entity including instrumental techniques, general theory, and even a metaphysical worldview. In fact Kuhn abandoned the latter use of the word `paradigm' in the `Postscript' to the 1970 second edition of his book and replaced it by `disciplinary matrix' (p. 182). Moreover, later on, Kuhn has even avoided the use of the term `paradigm,' as he has declared in an interview in the 1990s (Borradori, 1994, p. 166).

6. In this respect, theorists on education and computing (Papert, 1993) often employ Vygotsky's ideas to see the computer as a cognitive tool guiding and supporting the novice as he or she undertakes complex tasks by emulating processes and behaviors typical of an expert. Hence, the role of the computer is considered as one of a partner in the learner's construction of knowledge - a cognitive tool to be used to facilitate cognitive processes and thereby help build understanding.

7. However, recent criticisms to social constructivism strongly contest its applicability to science education (Kragh, 1998; Slezak, 1994a, 1994b; Phillips, 1997).

8. In this context, it would be better to be called `sociological constructivism' not to be confused with Vygotsky's social constructivism. However we risk this confusion in this section, as the term `social constructivism' has prevailed in the terminology of science and technology studies.

9. Here we adopt Brey's (1997) taxonomy of social constructivist approaches, which is a variant of Sismondo's (1993).

10. Brey (1997) reviews such theoretical changes in the areas of social consequences, excluded social groups, macro-level analyses, and normative and political issues.

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