MIND, CULTURE, AND ACTIVITY, 6(3), 170–195
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ARTICLES

The Riddle of Things: Activity Theory and Actor-Network Theory as Approaches to Studying Innovations

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This article compares cultural–historical activity theory (AT) and actor-network theory (ANT) as approaches to studying technical innovations. The concept of nature and society production in the ANT and the concept of activity in the AT have much in common as attempts to transcend the dualism between subject and object, nature and society. The symmetrical (ANT) and the dialectical (AT) interpretations of the concept of mediation are compared. It is suggested that the historically developed, artifact-mediated structure of human activity is instrumental in studying interaction and coevolution of social and material entities. Three limitations of the concept of generalized symmetry, or symmetrical mediation, become evident when the concept is used in empirical studies of innovation: First, it does not supply any criteria for defining the nature and scope of actors in a heterogeneous network. Second, it leads to an asymmetrical, Machiavellian analysis of innovation in which the contribution of designers, users, and nonhuman entities remains marginal. Third, it does not provide any explanation for the intentionality and competence of humans. It is suggested that these problems can be solved if the innovation network is studied as a network of activity systems. Nonhuman entities are included in the analysis as historically developed arrays of tools and raw materials of the activity systems. This approach is elaborated by analyzing an unsuccessful innovation process, the production of ethanol from wood through the use of cellulose-degrading enzymes. It is suggested that instead of applying the symmetrical semiotic language proposed by ANT in the analysis, a dialogue that utilizes the historically developed resources and languages of different thought communities is needed.

This article is part of an attempt to develop an approach to studying technical innovations from the premises of the cultural historical activity theory (AT). When I started work within the sociological studies of science and technology, actor-network theory (ANT) had recently raised an important challenge: The innovation process should be studied as a simultaneous development of an artifact and a network of actors connected to it. ANT formulated a general methodological maxim that seemed to me both interesting and complementary to AT itself: "Follow the actors, both as they at-

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tempt to transform society and as they seek to build scientific knowledge or technological systems" (Callon, Law, & Rip, 1986, p. 4). ANT raised the question of the creation of a new artifact as an issue of analysis.

Although these two approaches have a different disciplinary and philosophical background, in my mind, they also have in common several methodological endeavors. These include avoidance of monocausal explanations, an attempt to find a nondualist account of society and nature, taking seriously the significance of material artifacts, and studying the concrete networks of actors instead of interrelations between macro- and microscale phenomena. Both theories stress that resources for doing and acting are distributed and redistributed among man, artifacts, and environment. Both underline the significance of the independent activity of objects. However, because of their different theoretical background, they also propose different perspectives and solutions to studying these issues. These provide, nonetheless, complementary points of views and create a basis for dialogue.

I proceed with this article in the following manner. First, I briefly introduce the background of ANT and AT. Second, I compare some of the central concepts of AT and ANT. I argue that the concept of nature and society production in ANT and the concept of activity in AT have much in common as attempts to transcend the dualism between subject and object, nature and society. I proceed by comparing the concept of the symmetrical (ANT) and the dialectical (AT) interpretation of the concept of mediation. In the third part of the article, I discuss some of the problems of ANT used as an approach in the empirical studies of innovations. Fourth, I elaborate the activity theoretical approach to analyzing an innovation process by studying an empirical case, an attempt to construct a method of producing ethanol from wood by using cellulose-degrading enzymes. In the discussion part of the article, I compare the use of symmetrical vocabulary and dialogue as research strategies.

ABOUT THE BACKGROUND AND THE METHODOLOGICAL ENDEAVORS OF ANT

ANT has its roots in French philosophy and semiotics. Particularly, it has been inspired by the work and ideas of Serres (1974). On the other hand, ANT has evolved as part of the development of the constructivist sociology of knowledge, or what was later characterized as social studies of science and technology. I concentrate on this because I am studying ANT primarily as an approach used for innovation studies.

Instead of regarding facts as mirror images of nature or reality, the new sociology of science wanted to study how the scientific facts are being produced in laboratories and, via controversies, in research communities. Ethnographic studies on laboratory work were an attempt to do such an analysis (Latour & Woolgar, 1979). ANT was developed during the 1980s by Callon and Latour (Callon, 1986a; Latour, 1987) from the Ecoles des Mines de Paris, Centre de Sociologie de l'Innovation, and John Law (1987) from the University of Keele.

ANT is hardly a unitary theory and it has its own complex history. It could also be characterized as a program of methodological provocations that constantly challenge traditional categories in social sciences, introducing new sets of terms for their reconceptualizing. This way of theorizing stimulates thought, and I have learned much from it. However, it is difficult to define the hard conceptual core of the theory. In my reading, ANT can be characterized as a contradictory combi-

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nation of the two methodological concepts anchored to its history: the early form of ANT, the sociology of translation already implying the principle of Machiavellianism, or the translation of interests and related concept of force. The principle of generalized symmetry was first formulated by Callon (1986a, 1986b) and was further elaborated by Latour (1992a, 1993b). It became the most important theoretical concept of ANT in the 1990s.

The early form and a forerunner of the theory, the sociology of translations introduced the concepts of power and politics to characterize network relationships. The concept of translation was taken by Callon from the French philosopher Serres. Callon and Latour (1981) defined *translation* in the following manner: "By translation we understand all the negotiations, ... acts of persuasion and violence thanks to which an actor or force takes ... authority to speak or act on behalf of another actor or force" (p. 279). What is important is "the balance of forces irrespective of the nature and origins of these forces" (Callon, 1980, p. 209) and *transformation,* getting the forces involved "as if they were identical" (Callon & Law, 1982, p. 619). With the metatheoretical concept of force, it was possible to ignore the differences between entities and transcend the dualist distinction between nature and society and between human and nonhuman. "Strength and success lies in the ability to bind together forces, to make them compatible and equivalent. That is why we stress so strongly that they must be looked at in the same way, and dealt with using similar concepts" (Callon & Latour, 1981, p. 292). This is an early formulation of the need for a symmetrical language.[1]

A spokesman, an entrepreneur, or an innovator enrolls different actors into a network. The spokesman transforms the interests and forces of the other actors and makes participation in the network an obligatory passage point or necessity to them. The associations between human and nonhuman actors or elements build networks. The more actors mobilized, the stronger and more durable the network. The actor-network theorists compare the spokesman of new facts and technologies to Machiavelli's prince, "who is skillful in the art of managing variable and unexpected social forces" (Callon et al., 1986, p. 7). Technological artifacts are constructed like scientific facts:

> The problem of the builder of "fact" is the same as that of the builder of "objects": How to convince others, how to control their behavior, how to gather enough resources in one place, how to have the claim or the object to spread out in time and space. (Latour, 1987, p. 131)

In the latter part of the 1980s, the methodological principle of generalized symmetry was elaborated. According to this principle, the same kind of treatment should be given to both human and nonhuman elements of the networks (Callon, 1986b). Bloor (1976) formulated the first principle of symmetry in the sociology of knowledge. Sociology of knowledge used to explain true statements with a correspondence to nature and false statements with social reasons. According to Bloor, both should be explained symmetrically by social reasons. This solution was, however, according to Latour (1992a), a reduction in the sense of "bracketing" the material from the explanation. Society was supposed to explain nature. Thus one more turn was needed, a turn that gives explanatory priority neither to nature nor society. The generalized principle of symmetry suggests that the same

[1] When saying that all entities can be treated as elements in the struggle of power, Callon and Latour refer to Serres (1974), and to Hobbes (1978), whose sovereign became powerful by acquiring the right to be a spokesman of others. They also refer to Deleuze and Guattari (1972) and to Nietzsche's (1974) concept *will to power,* a determination to which all the entities and phenomena of reality can be reduced (Callon & Latour, 1981, p. 303).

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repertoire of vocabulary must be used in the description and explanation of the natural and the social (Callon, 1986a, p. 200). Because nature and society are produced in the same process, no change of register is permissible when we move from the technical to the social aspects of the problem studied: "The new generalized principle of symmetry follows directly from the development of science studies and, in my view, is their most important philosophical discovery" (Latour, 1992a, p. 282).

The extended principle of symmetry is realized by creating a symmetrical vocabulary. The terms of this language are adopted from the structuralist semiotics of Greimas (1979). Hence, "By the term 'actor' we mean, from now on, a semiotic definition by Greimas in 'Dictionnaire de sémiotique' (1979): 'whatever unit of discourse is invested a role,' like the notion of force, it is in no way limited to 'human'" (Callon & Latour, 1981, pp. 301–302).[2] On the basis of the principle of symmetry, the actor-network theorists characterize actor networks as heterogeneous networks or techno-economic networks (Callon, 1991), collectives of humans and nonhumans (Latour, 1991), patterned networks of heterogeneous materials (Law, 1992), or hybrid collectives (Callon & Law, 1995).

AT AND MEDIATION BY ARTIFACTS

The cultural historical theory of activity stems from a different background. Vygotsky (1982) founded it as an antidualist solution to the crisis of psychology during the first decades of the 20th century. In those days, psychology was characterized by two opposing conceptions. On one hand, human consciousness was studied as an autonomous agent independent of and opposed to the material environment. The method used in research was introspection: An individual observed his or her inner world and stream of consciousness. On the other hand, psychological processes were studied as an epiphenomenon of biology and physiology. Reflectology and behaviorism tended to explain consciousness in terms of elementary nervous mechanisms, using the concept of reflex or stimulus–response connection.

In the 1920s Vygotsky (1978) formulated a solution to how to transcend these two opposing but equally unsatisfactory explanations: the concept of *mediated action.* The relation between the human agent and the object is mediated by cultural means or artifacts. The basic types of these means are signs and tools. During socialization, an individual internalizes, by participating in common activities with other humans, the means of culture: language, theories, technical artifacts, and norms and modes of acting. Thus consciousness does not exist situated inside the head of the individual but in the interaction—realized through material activity—between the individual and the objective forms of culture created by the labor of mankind. Vygotsky (1978, p. 54) applied to psychology the philosophical concept of mediation formulated by Hegel (1979) and further developed by Marx (1964) on a materialistic basis. It is an issue of historical interpretation as to what extent Marx's idea of labor activity was a starting point for Vygotsky's analysis of arti-

[2]The Hobbesian conception of sovereign was preserved within the principle of generalized symmetry. In the first versions of generalized symmetry, a spokesman is a mobilizer of all kinds of forces (Callon, 1986a, p. 22). Élecricite' de France, a prime mover of the actor world "puts forward a list of entities and a list of what they do, think, want and experience" (p. 22). Here I see the seed of the central contradiction of ANT: The concept of the prime mover (spokesman, prince) is an utterly asymmetrical entity.

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fact-mediated activity (see, e.g., Davydov & Radzikhovskii, 1985). Anyhow, in the methodological discussion, it is fruitful to regard AT as an elaboration and continuation of dialectical materialism and Marx's historical anthropology, as proposed by Ilyenkov (1977), Lektorsky (1980), and Bakhurst (1991), among others.

Vygotsky concentrated on studying how a child internalizes the most important of all cultural means, language. He formulated the genetic law of cultural development, according to which a child's cultural development takes place twice, or on two planes (Vygotsky, 1981, p. 163). It appears first interpsychologically, in interaction between people, and second, within a child as an intrapsychological category. This law has a great significance outside the sphere of language learning and ontogeny. It is a general formulation of the mechanism through which the forms of material culture are internalized by an individual due to participation in collective material activities in the society. On the other hand, Vygotsky's theory of thought implied the reverse transition, from internal to external forms of thought; that is, externalization. In principle, it forms a basis for studying innovations as an externalized form of human activity and thought.

Later on, AT studied the social mediation of activity. Consciousness and meaning are always formed in a joint, collective activity (Leont'ev, 1978). As a result, the unit of analysis in studying human mediated activity is an *activity system,* a community of actors who have a common object of activity (Cole & Engeström, 1993; Engeström, 1987). In this model, social mediatedness is characterized by division of labor and rules mediating the interaction between the individuals in the activity system. The collective activity system, as unit of analysis, connects the psychological, cultural, and institutional perspectives to analysis. The study of activity ceases to be the psychology of an individual but instead focuses on the interaction between an individual, systems of artifacts, and other individuals in historically developing institutional settings.

PRODUCTION OF NATURE AND CULTURES AND COPRODUCTION OF OBJECT AND SUBJECT IN ACTIVITY: PARALLEL SOLUTIONS TO THE PROBLEM OF DUALISM

According to Latour, the modern constitution or worldview uses one-dimensional language that operates in the framework of opposite poles of nature and culture. Knowledge and artifacts are explained either by society (social constructionism) or by nature (realism). To transcend this dualism, a second dimension is needed. It is the process of nature and society construction that results in the stabilization of a strong network. By selecting this process as a unit of analysis, it is possible to understand the simultaneous construction of culture, society, and nature:

> Instead of being opposite causes of our knowledge, the two poles are a single consequence of a common practice that is now the single focus of our analysis. Society (or Subject, or Mind or Brain ...) cannot be used to explain the practice of science, since *both are results of the science and technology making.* (Latour, 1992a, p. 281)

The fact or artifact is transformed into a black box once the network of many actors has been stabilized: "The reason why we went to study the laboratories, active controversies, skills, instrument making, and emerging entities was to encounter unstable states of nature/society and to document what happens in those extreme and novel situations" (Latour, 1991, p. 287). The concept of science

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and technology making is, in my opinion, parallel to the concept of object-oriented, environment-transforming human activity developed by materialistic dialectics and AT. ANT raises the challenge of studying reality as transitional in its becoming and as trajectories of creation. This idea of becoming and change is one of the central methodological ideals of dialectics as well.

In "Thesis on Feuerbach" (Marx, 1984) and in several other works, Marx formulated the idea of object-oriented (*Gegenständliche*), material, practical activity as a solution to the controversy between old materialism and idealism. Marx (1964) presented a materialistic interpretation of the idealistic Hegelian conception of the objectification of mind in sensuous physical material. According to Marx, both subject and object are produced in work, in transformative interaction with nature. Man actually produces himself by transforming nature in production of things, by the construction and use of artifacts. Both the objects and subject owe their very possibility to exist to activity.

Feuerbach's anthropological materialism conceived man as a thinking body, an organism, that encounters the resistance of natural objects when trying to satisfy its needs. In his critique, Marx argued that this concept implies a receptive and contemplative conception of sensuousness. He suggested, instead, that man's relation to nature should be analyzed as practical activity; that is, a cooperative transformation of the world (as production, as construction of objects). This conception does not imply a Prometheus myth. It does not explain nature by intentionality or consciousness of a subject. On the contrary, it explains the subject and nature in the context of activity, the history of nature transformation realized by humanity. The result is a humanized nature, the world of artifacts as a precondition for human subjectivity.[3] On the other hand, man is naturalized. By using "the mechanical, physical, and chemical properties of objects ... as forces affecting other objects" (Vygotsky, 1978, p. 54) man also appropriates and internalizes these properties. Schmidt (1971) summarized Marx's concept of nature as follows:

> Marx—the nature-dialectician—did not limit himself to contemplating pre-human nature and its history, view reality "only in the form of the Object," nor despite of his admiration to Hegel, did he view reality "in the form of Subject." He insisted instead the indivisibility of the two moments. The awareness of this indivisibility lies in the core of the Marx's materialism. (pp. 30, 79)

The nature, culture, and production of ANT and the concept of work and object-oriented activity of the activity theory are methodologically parallel, basic solutions to the problem of transcending dualistic oppositions between nature and society, between the subject and the object: how to find a second dimension, an explanatory principle reaching outside the dichotomy. Latour (1993b) regarded the conception of "humanized nature" and "culture penetrated by nature" (p. 78) as mixtures of two pure forms. For dialectics it is natural to regard entities as a contradictory unity of different determinations. Man is a biological organism and a cultural being. An artifact is constructed, social, and natural. This contradictory nature is understandable only through their mutual determination through activity; that is, in constant mutual interaction and movement. Activity is a hybrid composed of subjects, tools, the object of activity, division of labor, and rules. The hybrid character of entities can—in my mind—be well understood through using these concepts.

[3] On the Marxian and dialectical conception of man and nature see Bakhurst (1991), Honneth and Joas (1988), Margolis (1988), and Schmidt (1971).

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Law (1994) characterized ANT as *relational materialism*,[4] and Latour (1993a) characterized it as *distributed monism*. Both terms underline that entities gain their identity only through other entities, through interactive relations. To me, AT and dialectical approach can largely agree on this point. In addition, the founders of ANT have stressed its nature as fluid materialism. ANT is a "theory that says that by following circulation we can get more than by defining entities, essences or provinces. ... It is a theory of space and fluids circulating in a non-modern situation" (Latour, 1997b, p. 2). Ontological choreography, constant interpenetrations, relations, and processes—not things—are important (Callon & Law, 1995). This emphasized the point that ANT seems to avoid using the concepts of subject and object, nature, and culture at all. The dialectical and activity theoretical approaches regard it meaningful and necessary to use them underlying, at the same time, to analyze how they evolve, are determined by each other, and change into one another. The thesis of the fluidity of transitions leaves contradictions, tension, and barriers of interaction aside. Their existence presupposes historically established identities, durability, and inertia of things.

The difference in dealing with dualistic conceptions between the two approaches becomes evident in Latour's (1993b) treatment of dialectics. He regarded dialectics as an attempt to rescue "with dialectical tricks, arrows and circles" (p. 57) the Great Divide, the distinction between the subject and the object. By this attempt the dialecticians proved to be the most modernistic of all. In the rescue process, they postulate mediations that, however, transmit only pure ontological qualities of either spirit or matter. Latour did not resort to references in his critique nor did he specify the content, or what the "tricks" of dialectics are. To shed some light on this problem, I compare the concepts of mediation and object as elaborated by ANT and AT.

THE CONCEPT OF MEDIATION IN ANT AND AT

ANT has developed the concept of mediation on several levels. First, it has been elaborated on the philosophical and the methodological plane, as a critique of modern constitution, realism, and social constructivism. Second, Latour (1992b) developed the concept of mediation by thought experiments, by analyzing examples of common technical artifacts. It would be reasonable to expect that the concept has also developed through empirical research on innovations. However, it seems to me ANT encounters an increasing number of difficulties when applying the symmetrical version of mediation, when analysis moves away from the methodological plane toward empirical analysis. In the empirical research, the symmetry tends actually to be converted to a radical asymmetry, Machiavellianism. I proceed in my analysis to compare the symmetrical and dialectical conceptions of mediation and to point out their common features, their differences, and their potentialities.

The concept of mediation has a central role in ANT's metatheory: "Nothing is, by itself, reducible or irreducible to anything else. Never by itself, but always through the mediation of another"

[4]Law (1994) saw a connection between social interactionism and ANT:

> Actor network theory is remarkably like symbolic interaction. But symbolic interaction with an added dash of Machiavellian Political Theory, a portion of (suitably) diluted discourse analysis, and a commitment to the project of understanding the material character of the networks of the social. (p. 100)

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(Latour, 1993a, p. 113). In Latour's analysis of modernism, the concept *work of mediation* is an event or a process that gives birth to and explains both nature and culture. It is a new focus of studies, the Middle Kingdom: "Nature and Society are not two opposite transcendences but one and the same growing out of the work of mediation" (Latour, 1993b, pp. 87–88). Whereas an intermediary simply "transports energy from one of the poles of the (Modern Constitution) ... a *mediator is an original event and creates what it translates as well as entities between which it plays a mediating role* (pp. 77–78). This could be interpreted by saying that instead of a monocausal explanation, a relational, interactional causality is needed. This definition of mediation resembles very much the basic principle of Hegelian dialectics, the relationship to oneself through another. In Hegel, the mind develops through the material and is mediated by it.

According to Latour (1993b), dialectics imply the social constructivist reduction in the form of the Prometheus myth: an all-powerful human agent imposing an arbitrary form on shapeless matter. In the *Homo faber* myth, we are viewed as sons and daughters of our own works (Latour, 1993b, p. 35). In reality, nonhumans also act, displace goals, and contribute to their redefinition (Latour, 1994, p. 38). This critique may hit the Hegelian dialectics that postulate that nature is socially constructed, reduced to a form given by the human mind and activity (Ilyenkov, 1977, p. 82). The Marxian concept of work and the concept of activity, do not, however, necessarily imply any such relation.[5]

Latour was right in that Marx's conception of work is asymmetrical. Although man as a biological organism is a part of nature, he also diverges from nature and positions himself against nature as a subject. This kind of subject–object relation should not be interpreted as a postulation of distinct ontological spheres. It is a relation developed in the course of human evolution. The early activity theorists, especially Leont'ev, took great pains in studying how forms of consciousness developed little by little within the increasing complexity of interaction between organisms and environment (see Leontyev, 1981; Luria & Vygotsky, 1992). This interaction developed from a simple metabolism to more complex forms of perception and orientation. This implies a gradual breaking of the direct, immediate, impulse-based relation to the objects of the environment. With the cultural development—characterized by communication and the construction and use of tools—a specifically human type of orientation and consciousness emerged. It also implies the capability of imagining and planning what the future may hold; that is, intentionality.

According to AT, the specifically human type of consciousness is needed to make sense of the relation between man and his environment. It is needed when the aim is to analyze, in a sensible way, the work of constructing associations between heterogeneous entities, the work of creating new assemblies of materials and humans. Although all entities of the assembly do have the power to influence, or "act," they are asymmetrical in regard to taking the initiative in the construction of associations.[6] This does not mean that subjectivity is a causal, explanatory principle. It is some-

[5]Marx outlined his concept of man, nature, and work and practical, object-related activity in *Economical and Philosophical Manuscripts of 1844* (Marx, 1984), the "Thesis on Feuerbach" (Marx, 1964), *Grundrisse* (1973) and in the first brief chapter of *Capital* (1990, pp. 125–177). This theorizing remained without further elaboration. The volumes of Capital developed the idea of alienated work under the specific circumstances of capitalism. Therefore, the creative and dynamic potential of concrete work process and the new technology also remained underdeveloped. In his early works, Marx used Enlightenment jargon (with essences, human powers, and domination over nature). This should not, however, prevent us from using the lasting kernel of Marx's anthropology and methodology.

[6]I find a signal of acceptance of such an asymmetry in Latour's (1994) statement: "The attribution to one actor of the role of prime mover in no way weakens the necessity of the *composition* of forces to explain the action" (p. 35).

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thing that is explained through mediation, artifact-mediated collective activity. It is a moment in material activity, a mediator of activity. Subject mediates things in activity.

In AT, the subject–object relation is a historical phenomenon that came into existence as a result of the biological and cultural evolution. ANT postulates a general theory of association of forces, regardless of what they are. Symmetry is sought by describing all entities with the same semiotic vocabulary. Whether this is a fruitful enterprise or not, I am not certain, as I point out.

MEDIATION IN ANALYSIS OF TECHNICAL ARTIFACTS: DISTRIBUTION, DELEGATION, OR WHAT?

Latour (1991, 1992b, 1994) elaborated the concept of mediation in his sociology of technical artifacts and technical mediation, mediation in the realm of technique. He developed his conception by using several simple and convincing examples of technical artifacts, such as the weight of a key, the road bump, the automatic groom, and the seat belt of a car. With these examples he showed how the human and the artifact are determined and transformed by each other. Technical artifacts have a script, an affordance, a function, or a program of action and goals (Latour, 1994). Consequently, action and agency must be explained by the combination or association of human and nonhuman actors. They also have a moral, being able to carry norms and influencing the behavior of humans. "We have been able to delegate to nonhumans not only force as we have known it for centuries but also values, duties, and ethics" (Latour, 1992b, p. 232).

Latour (1991) analyzed how skills and competencies are distributed among people and artifacts. He analyzed how contradictory interests and expectations of the different social groups are inscribed in the design of an artifact. In the analysis of introducing a weight to a hotel key, all the elements of the network are transformed and something new emerges (p. 105). This analysis is—to my mind—a nice piece of dialectics analyzing the changing subjects and objects and their relations.

> The program, "Leave your key at the front desk," which is now scrupulously executed by the majority of the customers is simply not the one we started with. Its displacement has transformed it. Customers no longer leave their room keys: instead, they get rid of an unwieldy object that deforms their pockets. If they conform to the manager's wishes, it is not because they read the sign, nor because they are particularly well-mannered. It is because they cannot do otherwise. ... The statement is no longer the same, the customers are no longer the same, the key is no longer the same—even the hotel is no longer quite exactly the same. (p. 105)

In speaking of how engineers delegate norms and programs of action to artifacts, Latour (1993b) renounced the concepts of *production, embodiment, objectification and materialization,* and *reification,* because these words would imply the Prometheus myth. Instead, he adopted from Serres the concept of *substitution* in analyzing mediation. He also used the words *displacement, transaction,* or *exchange of properties.* Mediation can also be characterized as *distribution of competencies* between humans and nonhumans (Latour, 1992b, p. 233).

Using the language of substitution and displacement Latour (1991) stated, "We simply ask: has a human replaced a non-human? Has a non-human replaced a human?" (p. 110). An automatic door closer, a groom, replaces a porter or a gatekeeper. An unreliable human is replaced by a reli-

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able nonhuman. The traffic light replaces the police officer. The road bumper is a sleeping police officer, so we are told. However, porters or gatekeepers were never hired to keep the door closed. They were hired for a variety of aims and tasks such as protection of private property, reception of guests, informing the masters of the house, and a variety of other concrete actions. In Finland, porters of restaurants select the right customers—by closing the door selectively—and throw out the wrong ones. In Latour's examples, only simple operations are replaced, not the policeman or the porter. Latour (1992b) also held a similar view when analyzing the groom. An unskilled nonhuman groom presupposes a skilled human user (p. 232). This can surely be seen as an asymmetrical distribution of skills and competencies.

To better understand the mediation, the nature of different kinds of mediating artifacts, their functions and interrelations in activity need to be analyzed. In AT, such an attempt has been made by studying the functional, historically evolving interrelations between different kinds of artifacts and their relation to the structure of activity. Leont'ev (1978) defined three interrelated levels of activity: collective activity driven by a complex social motive, individual goal-oriented actions, and operations and routine ways of doing things and using tools. Operations are easily transferred to machines and artifacts. Actions presupposing the use of conceptual tools or imagination are already much more difficult to delegate to nonhumans, as experiences of expert systems demonstrate. The "skill" of finding and inventing new associations between entities is a collective enterprise, analyzable in terms of an assembly of mediating cultural resources of the participants and special symbolic artifacts that make orientation to the future possible.

ARTIFACT AND THING AS A CONTRADICTORY UNITY OF THE HUMAN CONSTRUCTION AND PREHUMAN NATURAL QUALITY

AT agrees with ANT in emphasizing the significance of the active nature of artifacts and objects. As a cultural–historical approach it sees the artifacts as created by human history, by collective material activity. An individual meets these constructed artifacts as an objective and given world of things. The extremely slow development of tools in human phylogenesis illustrates that their creation was not a Prometheus story, but a complex evolutionary process related to changes in human biology and social relationships.[7] However, as a result of this evolution, cultural artifacts as a specific kind of objects used as mediational means carry objectified norms of cognition, object hypothesis, and purposes of use (Lektorsky, 1980, p. 137).

Artifacts and things are constructed and mediated by human activity, but do they have an evolutionary history before the emergence of man and his history? Does such a prehuman existence have any significance for the study of production and use of artifacts? How can we explain that things are not bent to our plans and often resist the attempts of construction? I deal with this problem by looking at the microfungus *Trichoderma reesei*, a producer of cellulose-degrading enzymes. It is a principal entity or nonhuman actor in an innovation that I study in this article. The

[7]The oldest stone tools, the Olduvai tools, were used between 2.4 and 1.5 million years ago, presumably by *Homo Habilis*. These tools changed and varied very little during that period (see, e.g., Schick & Toth, 1993). The developmental period of the producer of Acheulian tools, the conqueror of the world, *Homo Erectus*, was 1 million years. It is during the last tens of thousands of years that a rapid cultural change with production of an increasing variety of artifacts was initiated.

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researchers of the project used the enzymes produced by *Trichoderma* as a means of degrading cellulose into sugars.

The story of *Trichoderma* is human history. *Trichoderma* was "discovered" when the cotton-made clothes and tents of the U.S. Army were destroyed in a tropical environment in World War II. *Trichoderma* was found guilty for this destruction. Its enzymes degraded the cellulose of cotton into sugars, which it then used for its growth. The U.S. Army's Natick Laboratories picked up the organism and studied it as a producer of cellulose-degrading enzymes. The laboratory made an attempt to use it in the 1960s to decompose communal wastes. A biotechnology laboratory in Finland received a *Trichoderma reesei* strain from the Natick Laboratories in 1973 and planned to use its enzymes for the production of ethanol from wood. The strains of *Trichoderma* were mutated by radiation and chemicals. As the result of these manipulations, the strain created in 1978 in Finland (VTT–D–80133) had a fourfold capacity for cellulase production when compared to the laboratory strain received in 1973. We know *Trichoderma* only through this human history. The laboratory strains are genuinely human constructions that do not exist in nature outside the laboratories.

However, the microbiologists tell us, on the basis of fossil data, that wood-decaying fungi were born together with conifer forests (Taylor, 1990). According to this conception, *Trichoderma reesei* has a history of 300 million to 400 million years.[8] Can we ignore the prehuman history on the grounds that we can know it only through what is reconstructed from paleontological data? Does prehuman history have any significance? I think it supplies a credible explanation for the resistance of things and entities. *Trichoderma* was not malleable. Later in the article, it will be described in more detail, that the activity of *Trichoderma* enzymes proved lower than the researchers had expected and hoped for. It did not degrade the wood cellulose efficiently enough for the volume of industrial production planned by the biotechnologists. Strange things happened: When *Trichoderma* was modified genetically to add to it some characteristic, its growth decreased in the fermentor. There was a limit for human uses of *Trichoderma.* The postulation of evolutional propensities of entities that precede human history is needed to avoid voluntarism and to serve as an explanation for the independent active properties of entities, although these properties are only known through human activity and experimentation. In that sense, it is not without reason to state that *Trichoderma reesei* contributed to the construction of ethanol production with its evolutionally developed natural function to degrade cellulose into sugars to get energy for its life processes and growth. What the geneticists, microbiologists, and fermentation engineers did was to use and transform this capability and associate it with a new kind of hybrid constellation, ethanol production from wood. Only owing to such attempts do we know anything about *Trichoderma reesei* and its life processes. However, in my mind, it is not satisfactory enough to say that *Trichoderma reesei* is a social construction without also saying simultaneously that it is transformed, appropriated, or humanized nature. Two different vocabularies are needed to capture the contradictory nature of things. An example of such a treatment is Kohler's (1994) analysis of *Drosophila* (banana fly) genetics. He argued convincingly the need for understanding the dual nature of an experimental creature. *Drosophila* is a biological organism and a piece of technology at the same time. It has a natural

[8]The human history of microbes is short compared with their evolutionary history. The use of microbes in producing wines, beer, and bread started about 8,000 years ago. Pasteur formulated the theory of microbes and started laboratory studies of microbes about 130 years ago. Interaction with *Trichoderma* started about 50 years ago.

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history and a history common with man. The coevolution of organisms and men has two aspects. First, by changing the environment, man has influenced the living conditions and morphology of organisms. Second, man deliberately uses and molds organisms as technology and agents serving different human purposes (e.g., *Trichoderma* as a "factory" of cellulose-degrading enzymes for ethanol production).

A social constructivist would state that the prehistoric evolution of *Trichoderma reesei* is just a story, a construction of paleontologists and microbiologists. I would ask whether the social constructivist really believes that microbes are 130 years and *Trichoderma* 50 years old instead of 350 million years old. It is not fruitful to argue about philosophical questions like this without leaning to the cosmology and conception of history constructed by the special sciences (like physics, astronomy, biology, geology, and paleontology). The solution to this problem is not regarding entities as either preexistent (realism) or constructed (social constructivism). Neither can it be solved by adopting a unitary semiotic terminology. The suggestion of using the two registers consciously discards the contrast between realism and relativism as unfruitful.

MEDIATION IN EMPIRICAL STUDIES OF INNOVATIONS: THE THREE PROBLEMS OF GENERALIZED SYMMETRY

The central methodological principle of ANT is the principle of generalized symmetry. However, in empirical analyses of innovations, another chronologically preceding principle, the principle of Machiavellianism, seems to dominate. These principles contradict each other. According to the principle of Machiavellianism, the actor, the prince, the innovator, the spokesman, is human. According to the principle of generalized symmetry, the actor can be either human or nonhuman. Why does this kind of shift of principles take place? I think the reason lies in the limitations of the symmetrical version of mediation. I see three interrelated problems in the use of symmetrical language in the analysis of innovations: the problem of structuring the analysis of the network and selecting the relevant elements or actors, the problem of silent actors, and the problem of human capability or intentionality in explaining the establishment of network associations.

The first problem concerns the delineating and structuring of the description and analysis of heterogeneous networks. Due to the heterogeneity of networks and the principle of generalized symmetry, no criteria for defining the nature and scope of actors can be presented in advance. Latour said that the concept of network "is also a way of getting rid of system and structure" (Crawford, 1993, p. 20).[9] No theoretically relevant elements of the network can be discerned in advance. The other side of the approach is the goal of complete description serving as an explanation: "The description has to cover all details, since every detail counts" (Callon, 1991, p. 155). If the object of research is an innovation process, the task seems hopeless. In any innovation network, the number of potential elements is almost unlimited, and ANT has difficulties selecting the relevant actors and structuring the analysis of relationships between them. At this point, I think ANT faces the same problem as positivistic empiricism did: How is it possible to decide what is important and essential and what is not without theoretical preconceptions?

[9] "There are neither wholes, nor parts. Neither is there harmony, composition, integration nor system. How something holds together, is determined in the field of battle, for no one agrees who should obey and who command, who should be the part and who the whole" (Latour, 1988, p. 164).

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This problem leads us to another one, the problem of silent actors. This is comprised of two interrelated parts: the human asymmetry and the generalized asymmetry that omits the analysis of the nonhuman elements. It seems as if in the empirical accounts of innovations the most prominent actors, those speaking most loudly, tend to be selected: innovators, managers, and politicians, the princes of network construction. This has been called by Star (1991) a managerial or an entrepreneurial model of innovation and networks. The empirical accounts seem to resort to Machiavellianism; that is, to extreme asymmetry instead of generalized symmetry. The work of engineers and users remains marginal. This human asymmetry is problematic, as the work of the actual construction of associations between the human and nonhuman is omitted with it (Button, 1993). Consequently, the contribution and resistance of nonhuman elements also remains marginal and is involved in the analysis mainly as a rhetorical resource used by human actors in their controversies.

This can be noted in two authoritative analyses, handling the cases of the combat aircraft TSR2 and the Aramis mass transit system. Law's (1988) analysis of the TSR2 includes a rich analysis of the design process with engineering problems connected to the expectations of the Army, Navy, and Treasury. Law, however, pointed out that the story of the rise and fall of the TSR2 is a story of "political and bureaucratic struggle" (p. 47). The analysis of the nonhuman elements is not included in the story. In Law and Callon's (1992) analysis of the TSR2 in "The Life and Death of an Aircraft: A Network Analysis of Technical Change," the engine problem is mentioned and used in connection with the analysis of network construction. In Latour's (1993a, 1996) account of Aramis, a public transportation system, the engineering work and problems—let alone actions of the nonhuman elements—are practically missing. At this point, I can largely agree with the comment presented by Czarniawska (1997) on Aramis:

> In Bakhtinian terms the author of Aramis uses variegated speech, which says a lot of his authorial talents although he does not achieve symmetry between humans and non-humans which is his aim. If anything, he magnifies the asymmetry. The reader does believe (unjustly so) that mayor Chirac owns a voice, but not for even a moment that Aramis does. (p. 19)

The third problem concerns the analysis of the role of human cognition, intentionality, and learning in the innovation process, ANT's "complete indifference in providing a model of human competence" (Latour, 1997a, p. 4). Even if we do not give any privileged causal role to cognition and intentionality, the conscious human anticipation plays a crucial organizing role in the innovation process. As a matter of fact, ANT does have a theory on human competence based on the idea of the prince. It is that of the competence in negotiating and exercising power (enlisting, mobilizing, etc.). Although power is an important aspect of networking, it is a unilateral conception. It does not study the mediating cultural resources, from the basis of which the actors participate, formulate plans, and contribute to the network construction. It ignores such phenomena as learning, development of expertise, complementarity of resources, and know-how in network construction.

In the following, I study how an activity theoretical approach would solve these three problems. I do it by using as an example a case of an unsuccessful innovation, an attempt to develop an ethanol production system based on enzymatic hydrolysis of wood. The endeavor was being attempted between 1986 and 1992 in the collaboration of a research laboratory, the Biotechnology Laboratory (BIO) of the Technical Research Centre of Finland; an ethanol and enzyme producer (Alko); and a pulp and paper producer, Metsäliiton Teollisuus. I study the process as an object and artifact construction, as a trajectory. I analyze it as a process in which a subject (in this case a cel-

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lulose research group), an object (production of ethanol by enzymatic degradation), means and tools of construction (microbes, methods, apparatus, and models), and social relations (a network of activity systems participating in the construction) are simultaneously being constructed and transformed. The case is presented here to illustrate some of the basic conceptions of the activity theoretical approach and should not be taken as a fully elaborated empirical analysis. It has been presented in detail, in its own right, in more extended empirical papers (Miettinen, 1996a, 1996b, 1998). The activity theoretical approach—as any approach—is be elaborated and shows its viability through the ongoing and future empirical studies.

HOW TO STRUCTURE THE ANALYSIS OF A HETEROGENEOUS NETWORK I: OBJECT CONSTRUCTION AND THE VTT BIOTECHNOLOGY LABORATORY

How to structure the analysis of an innovation network? The same question can be formulated by asking what is the basic node of the network. AT regards a historically formed local activity system or a community of practitioners (Cole & Engeström, 1993) as the node of a network. An object-oriented mediated activity is a historical formation with its internal dynamics. It is in itself a hybrid comprising the subject, object, signs and tools, the community, rules, and division of labor. It is therefore a locus within which the coevolution of the cognitive, material, and social in the innovative activity takes place.[10] The mediated structure of the activity provides a basic conception for studying the change and interaction between entities. The interrelation of the capacity and knowledge of the subject, the systems of means (tools and representations) used, and the object to be constructed is essential in the analysis.

Local activities participating in the construction of a new object form an innovation network. The development of the network is not analyzed primarily in terms of persuasion and power, but in terms of the cultural resources the participating activities mobilize in the construction process, and in terms of learning associated with this collaboration. According to AT, the interests of the actors are also based on their historically formed cultural resources. To study the significance of nonhuman elements, the concrete process of design and engineering work, as well as the use of the artifact, must be included in the analysis.

I start the analysis by studying the construction of a new object in the VTT Biotechnology Laboratory, the initiator of the development project. In 1974, the VTT Biotechnical Laboratory turned to the Finnish National Fund for Research and Development (SITRA) for financing of a project to produce ethanol from wood or other cellulosic materials. The project was started with the participation of and financing in part by two Finnish companies, Alko, the Finnish alcohol monopoly, and Metsäliiton Teollisuus, a pulp and paper producer. The research on the hydrolysis of cellulose and the production of ethanol, lasted from 1975 to 1981. Ethanol was the main application of the cellulase research until 1983.[11]

[10] Latour (1994) also spoke about collectives, saying, "To view people and non-humans as interacting within collectives, ... we need to know what a collective, an institution, and corporate body are" (p. 49).

[11] Wood, cotton, straw, and hay are lignocelluloses. The lignocellulose structure is composed of three fractions: cellulose (40%–45%), hemicellulose (30%–35%), and lignin (20%–25%). Cellulose and hemicellulose fibers are composed of chains of sugar molecules. The trivial names of enzymes refer to the substrates in which the enzymes catalyze reactions. They are formed with the ending *-ase*. Enzymes that degrade cellulose are called *cellulases*, and enzymes that degrade hemicellulose are *hemicellulases*.

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The production system to be constructed was composed of three main processes: the production of enzymes by microbes, the use of enzymes to degrade cellulosic materials into fermentable sugars, and fermentation of sugars into ethanol or other chemicals. These processes were also the main phenomena studied in the laboratory (see Figure 1). The research community and the means of construction were established together with the new object. Relatively autonomous project groups, including researchers with different disciplinary backgrounds, were formed to construct the key parts of the projected production system: the development of microbial strains, the optimization of the fermentation process, and the degradation of cellulose.

Each group acquired and developed instruments, materials, and methods to construct and develop their subobject. The researchers in charge of the projects represented different fields of science and technology. Each group also had, in some respects, its own network of collaboration. The optimizing of the fermentation process of the pilot fermentor, for instance, was carried out together with the process engineers of the Helsinki University of Technology. The full-scale hydrolysis and production experiments were carried out with the raw materials and fermentors of the industrial partners.

The development of the pilot fermentor and the fermentation process at the laboratory is a good example of the construction of a hybrid object. The production process is composed of a fermentor, a metal container with pipelines, valves, moving mechanical parts, and sensors. The group developed a computer program for the automatic control of the enzyme production. The program is based on the knowledge of microbe behavior and the process conditions. A mathematical model of enzyme production was constructed to make the computer program. A pilot fermentor is a complex system comprising mechanical equipment, living organisms, organic materials, chemicals, meters, sensors, a computer, and a computer program. On the other hand, this object was a tool for producing cellulases for the hydrolysis experiments and a means of simulating the enzyme production for a mill scale.

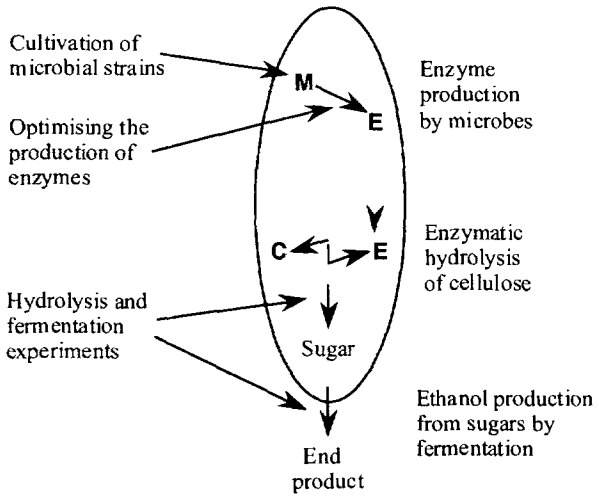

FIGURE 1 The structure of the object and the organization of cellulase research at the VTT Biotechnology Laboratory from 1972 to 1983. M = microbe; C = cellulose; E = enzyme.

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The construction of the experimental procedures and enzyme production was at the same time the construction of the tools for research and development work. An object (a microbe, an instrument, a theoretical model, a sample of cellulose substrate) can be either a tool or an object in research activity. Nothing in the physical constitution of an object can determine whether it is a means or an object of activity. When being an object of cognition and transformation, it is an object of activity. Once stabilized, it is transformed into a means of activity.

These transitions can be characterized by studying the research on the fungus *Trichoderma reesei.* The method of developing high-production microbial strains was the object of activity in the first phase of the *Trichoderma* studies, in 1976 and 1977. It soon turned into a means for developing *Trichoderma* strains. When a stable high-production *Trichoderma reesei* strain was reached in 1978, it turned into a means of producing enzymes, first for hydrolysis studies in the laboratory, and later as a means of industrial production of cellulases. When recombinant DNA technology was later used to modify the production profile of *Trichoderma,* the fungus turned again into an object of research and development.[12]

The interactive coevolution of the cognitive (vision and hypothesis of ethanol production based on enzymatic hydrolysis of wood), material (substrates, raw materials, organisms), and social (division of labor, project groups, and their networks) can be clearly seen. The object to be constructed is the organizing principle. The research community was organized according to the main elements and processes of the hybrid object.

HOW TO STRUCTURE THE ANALYSIS OF A HETEROGENEOUS NETWORK II: THE NETWORK OF ACTIVITY SYSTEMS CONSTRUCTING THE ETHANOL PRODUCTION

The ethanol production was studied in two projects in the years 1974 to 1981 with the participation of three partners. An ethanol production system was the object of the innovation network (see Figure 2).

Why did the partners of the innovation network participate in the object construction? ANT focuses on the process of mobilizing and enrolling actors in the network by translating their interests and goals. The empirical ANT innovation studies are case histories and, therefore, use history as a part of the analysis. This is, however, implicit, and it remains open in what way history forms the basis for the formation and change of interests. I think AT can contribute to articulating the significance of history.

The motive for participating in the construction of an object can be understood in reference to the participating activity system's attempt to expand, redirect, or transform its historically formed basic activity to solve a contradiction or a central problem of the activity. An emerging new motive can be characterized as an attempt to solve dilemmas and problems in the activity or to find a new possibility for extending the basic activity. This can happen by creating a new product, by finding a new complementary raw material, or by using new ways of using the tools and know-how at hand. These kinds of motives can be characterized as transformative interests be-

[12]About methodological significance of object–tool distinction, see Engeström and Escalante (1995).

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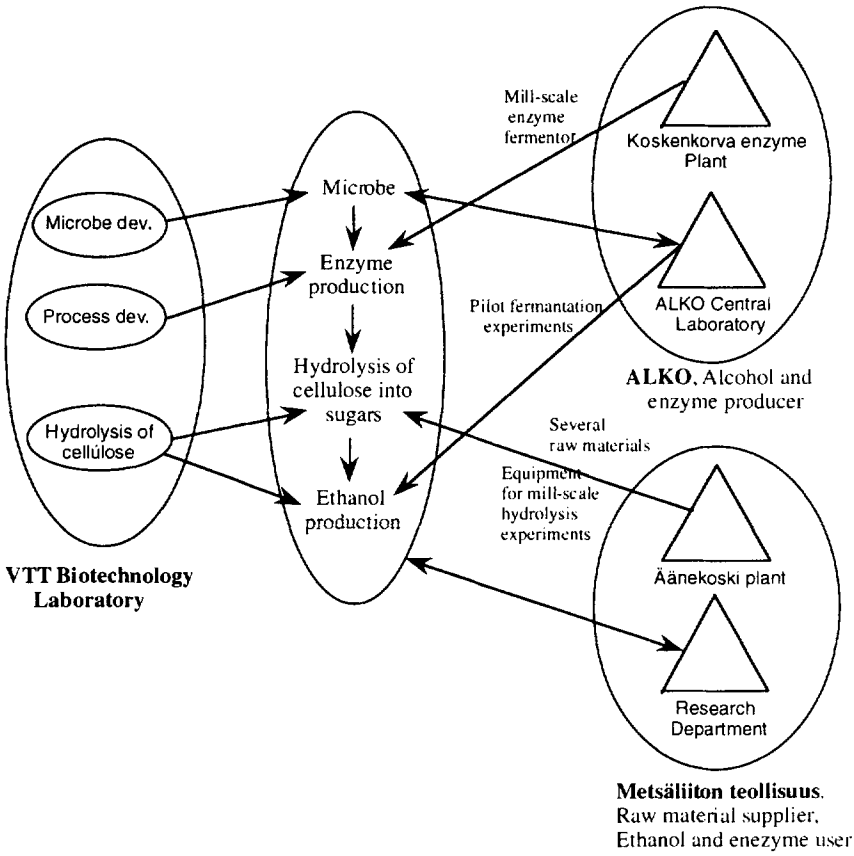

FIGURE 2 Production of ethanol as the object of the innovation network. Alko = Finnish alcohol monopoly; Metsäliiton Teollisuus = a Finnish pulp and paper company.

cause they are related to the transformation of a collective activity. Consequently, they are not analyzable in terms of the goals of individuals. The term *transformation* expresses well the simultaneity of the culturally constrained and the open nature of the construction of the facts and artifacts. Behind the transformative interests, there looms the reality of dilemmas and contradictions of the evolving activity systems.

Both of the firms participating in the ethanol research presented to the funding organization SITRA their long- and short-term project goals related in memos written in 1977 by the research managers of the firms. Alko explained that in 1974 the supply of sulfite spirit, the raw material of ethanol, was sharply diminishing because many sulfite pulping mills were closed in Finland in the 1970s.

> From Alko's point of view, the project focused on examining, whether it is possible for sugars obtained by enzymatic hydrolysis of cellulose to be used in commercial production of alcohol in order to substitute the increasing import of sulfite spirit. (Alko Report for SITRA, 1977, p. 1)

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Alko resolved this problem by assisting with the foundation of a new sulfite spirit plant in Finland. Second, Alko's fermentor at the Koskenkorva plant had extra capacity for utilization. Mill-scale experiments during the projects showed that the fermentor could be used for the production of cellulases. Alko stated that it would not be feasible to produce cellulases for ethanol production only. However, if they could be used in the pulp and paper industry as well, the production of cellulases might be a feasible option worth studying further.

Metsäliitto was interested in finding a use for its abundant cellulolysic waste materials from pulp and paper production. These materials are less valuable and difficult to dispose of. Metsäliitto wanted to turn them into valuable raw material. Metsäliitto was also a user of ethanol with its own ethanol production. Metsäliitto presented six possible uses for cellulases. Two of them concerned immediate problems in its production activity; for example, the utilization of wastes of the Savon Sellu plant. Four of them were longer term potential process innovations. The most important of these was the use of cellulases in mechanical pulping to save energy. In both cases, the construction of the object can be characterized as a transformation or an extension of the present object of activity and the corresponding tools and know-how.

Industrial corporations are aggregates of activity systems. From Alko and Metsäliiton Teollisuus, four activity systems or communities participated actively in the ethanol project. The Central Laboratory of Alko and the Research Department of Metsäliiton Teollisuus had a multiple role in the project. They acquired support from the corporate management, studied different potential uses of enzymes for the corporate activities, and planned and organized the research work. The Koskenkorva enzyme plant and the Äänekoski yeast plant participated in the work because of the raw materials pilot and industrial-scale production facilities they could provide.

The object was not constructed only discursively. Enzymes for the hydrolysis experiments were produced by the fermentor of Alko's Koskenkorva plant. The waste materials of Metsäliiton Teollisuus from Äänekoski were used as substrates (or raw materials) in hydrolysis experiments. The mill-scale experiments were made with the equipment of the Äänekoski plant. The fermentation of the hydrolysates into ethanol was made by the equipment of Alko's Central Laboratory. The new object was literally constructed with the material resources and know-how possessed by the participants. It is also evident that these resources were complementary in relation to the object to be constructed.

The material elements of the network influenced the construction of the subject, the research community. The waste liquor of the Savon Sellu plant contained a considerable amount of hemicellulose, the second main fraction of lignocellulose. The enzyme mixes constructed to degrade cellulose-rich substrates could not degrade these raw materials. It was, therefore, necessary and legitimate to redirect the research on the production and biochemistry of hemicellulose-degrading enzymes. The VTT Biotechnical Laboratory was later (in the 1990s) known for its advanced know-how on the production and use of hemicellulases.

Other activities of the network also changed. The Koskenkorva fermentation plant's people learned how to produce cellulases. Alko's Central Laboratory started to study cellulases and the *Trichoderma reesei* technology at the beginning of the 1990s. Later it became a producer of cellulose-degrading enzymes. The ethanol production never started, but the means and know-how remained and developed further. The participants found other uses for the enzymes.

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THE CONTRIBUTION AND RESISTANCE OF *TRICHODERMA REESEI* AND WASTE WOOD

At the beginning of the 1980s the cellulase research program, with its conception of the total hydrolysis of cellulosic materials into sugars, experienced a crisis. Several interrelated factors contributed to this.

First, the key elements of the process, enzymes and the substrate, did not act as hoped for and expected. The most promising raw material for enzymatic hydrolysis was the abundant waste wood from forest harvesting and saw and pulp mills. This material included bark, branches, and sawdust. It was very resistant to hydrolysis. Enzymes could not enter the structure of the wood, and the structure had to be somehow broken to make it accessible to cellulases. The researchers tried to remove the obstacle by studying pretreatment methods that would break the physical structure and make the wood accessible to enzymatic attack. One of the methods, steam explosion, was studied at the VTT Biotechnical Laboratory. This method, however, used a great deal of energy and was expensive, thus raising significantly the costs of enzymatic hydrolysis. The problem of pretreatment remained unsolved. In addition, it turned out that the intended main raw material, waste wood from harvesting, would have cost too much. The material lay dispersed in the forests, and its collection would have required the construction of a new transportation infrastructure.

An economically feasible utilization of wood presupposed an efficient hydrolysis of the substrate. However, the cellulases did not function as expected. The capacity of one weight unit of enzyme to degrade a substrate in a given time is called the specific activity of the enzyme. Experiments at the VTT Biotechnology Laboratory revealed that cellulases had low specific activity. Amylases, the enzymes used in the degradation of starch, were the natural frame for comparison. The specific activity of the cellulases was hundreds of times lower than that of the amylases. Consequently, large amounts of cellulases would have been needed for the hydrolysis of cellulose. Moreover, cellulases were—and still are—relatively expensive enzymes. This made the possibility of a large-scale industrial process unlikely:

> *Trichoderma reesei* has played a central role in world-wide endeavors aimed at biotechnical utilization of cellulose materials. ... A few general facts should be pointed out, both good news and bad news. First the good news ... *Trichoderma reesei* mutants are efficient producers of a variety of enzymes, including those necessary for the hydrolysis of cellulose and xylan. ... Then the bad news. The specific activity of *T reesei* cellulase is low. (Linko, Rättö, Viikari, & Bailey, 1993, p. 372)

However, the low specific activity of cellulases and the resistance of the raw material to enzymatic hydrolysis were not an obstacle, as such, as biological and chemical processes, to the system. The significance of the actions of the nonhuman elements—whether they were an obstacle or not—are definable only in relation to the usability and price of the commodity. In the case of ethanol production, the significance of the activity of enzymes and the structure of raw material gained their meaning through their contribution to the price of ethanol in relation to the competitive product, the oil fuel. Oil prices began to fall in 1983. Four Finnish companies interested in the production of ethanol from wood had made a feasibility study of an ethanol-producing plant in 1982. The calculations showed that production would be unprofitable. As a result, the funding for ethanol production was cut.

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INTENTIONALITY MEDIATED BY MODELS

The future-oriented human intentionality is not an internal capacity of an individual. It is mediated by cultural artifacts and is characterized by constant transition between the subjective and external forms of activity. This transition was analyzed by Vygotsky (1978), who used the terms *internalization* and *externalization.* Externalization implies the transformation of culturally given means and forms of action.

Wartofsky (1979) suggested a three-level typology of artifacts to be used in such an analysis of activity (p. 202). Tools are primary artifacts. Secondary artifacts, such as models, are either externally embodied or internal representations. They are used in the preservation and transmission of the acquired skills or modes of action. They synthesize the ways and procedures of using instruments and materials. Wartofsky's third level of artifacts consists of "alternative imaginative perceptual models, that are representations of possibilities which go beyond present actualities" (p. 208). Engeström (1987) regarded the hierarchical relation among the three levels of artifacts as essential. Secondary and tertiary artifacts are used as instruments for the cooperative, communicative, and self-conscious shaping and controlling of the procedures of using and making technical tools (p. 61). They are therefore essential in the analysis of the subjective and intentional, as well as the collective and communicative dimensions of activity.

A model of ethanol production from birch chips was first published in 1981 (see Figure 3). It is a model of a possible industrial-scale production system using a specific raw material. It is an example of a tertiary artifact. It has several functions in the activity. It synthesizes and generalizes

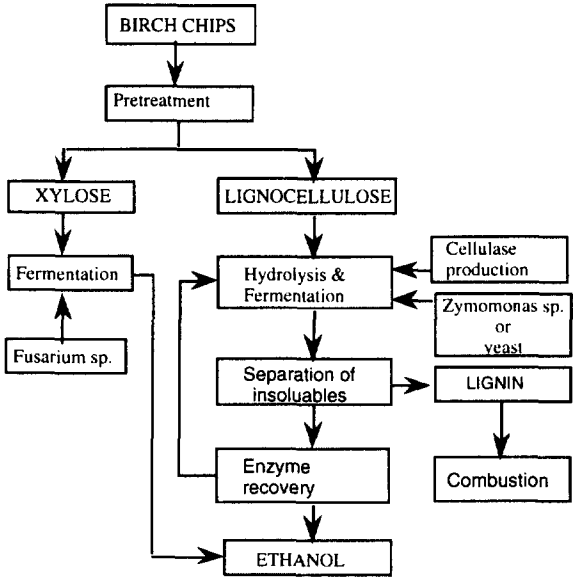

FIGURE 3 A diagram for the production of ethanol from birch wood. From "Ethanol from cellulosic materials," by L. Viikari, M. Linko, and T-M. Enzin, 1981, *Proceedings of the Ekman–Days International Symposium on Wood and Pulping Chemistry, 4,* p. 18. Copyright 1994 by Authors. Reprinted with permission.

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the modes and results of actions, carries and transmits purposes, and orients to the future. The model summarizes what has been achieved in the research thus far. Parts of the model were successfully tested in laboratory experiments.

The model is, simultaneously, a working hypothesis and a research plan: Two problems remained to be resolved in the research. The physical structure of birch wood must somehow be broken to make it vulnerable to the enzyme attack. No feasible technology for this was available at the time. For that reason a project on pretreatment was started in 1981. Furthermore, the hydrolysis of the cellulose fraction of the raw material was not complete enough to allow for an economically feasible industrial system to be born. The research aimed to solve these problems and to transform the model into a new form of existence: a pilot production system. The model also serves the construction of a future industrial system and, therefore, contains a social significance and motive: the idea of developing an alternative to a nonrenewable resource, oil. Having these characteristics, the model serves as a bridge between the past and the future in the activity. This model is a carrier of what Law (1988) characterized as a technological scenario, an imaginary sociotechnical world, that suggests how the world should be and how this might be achieved (p. 66). This kind of tertiary artifacts are a crucial vehicle for the human capability to plan new networks and mobilize other actors in the networks.

DISCUSSION

In this article, I suggested that AT supplies conceptual tools for solving the three problems of ANT's principle of generalized symmetry. First, for the structuring of the study of heterogeneous networks, it was suggested that an object-oriented, culturally and socially mediated local activity system be adopted as a unit of analysis for a node in the network. The object-oriented mediated structure of activity suggests a way of analyzing the interaction and coevolution of the various entities within the activity. Second, it was suggested that to avoid the managerial or Machiavellian analysis of network construction and to uncover the contribution and resistance of nonhuman entities, the work of engineers and users must be included in the analysis. Third, I suggested that to deal with the human competence and intentionality in a nondualist way, an analysis of a special kind of artifacts, future-oriented tertiary artifacts, is needed.

I suggested that the subject–object distinction and the methodological ideal of studying heterogeneous elements and their interactive coevolution in science and technology are compatible—given that subject or object are not understood as something given, unchangeable, or causally privileged. In the activity theoretical approach, the subject-object distinction is seen as a historically developed and constantly changing relation between man and nature, in which both are transformed and changed. Thus explained, the subject–object relation turns into a necessary conceptual tool for structuring the study of scientific and technical practice.

I believe that the attempt to create a semiotic symmetrical vocabulary is not a very promising methodological endeavor for two reasons. Callon and Latour (1992) said that they do not deny differences. They struggled against ahistorical, a priori, hierarchically given differences (p. 356). It seems to me, however, that also historically formed differences between entities are left without proper attention. I believe that taking these differences into account is essential in the analysis even if monocausal explanations are renounced. This does not concern only the distinction between human and nonhuman. The acceptance of symmetry means, for instance, that the problem

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of historically changing relations between science and technology is no longer interesting. To me, this issue remains interesting. I also think that the historical difference and interaction between everyday thinking and scientific thinking is a profoundly interesting problem. A French social psychologist, Moscovici (1984) regarded it as a key factor in understanding modern consciousness. Here again the study of the interaction and fusion of different thought forms presupposes a distinction made on the basis of their historical origin.

Another problem of a symmetrical vocabulary is that it renounces the historically formed specific vocabularies. The attempt to create a symmetrical vocabulary resembles the project undertaken by the behaviorists at the beginning of the century, although the epistemological program of the two approaches is radically different. Watson (1913) boldly declared, "The behaviorist, in his effort to get a unitary scheme of animal response, recognizes no dividing line between man and brute" (p. 158). The behaviorists established a research program, in which the results of animal experiments were generalized and given the status of general laws of learning, including human learning. The program was a failure and it is has been used as an example of reductionism, of an attempt to explain social and cultural phenomena with the principles drawn from biology.

The development and use of the symmetrical vocabulary implies giving up vocabularies particular to different fields of science and technology. Such an attempt tends to result in a monological language of social scientists that ignores the rich conceptual culture and the knowledge base provided by scientists and engineers studying the different natural and technical entities and phenomena.[13] The significance and contribution of the nonhuman elements in object construction must be included in any analysis. There is no other option than to resort to the mediational means that the development of culture—results of science and engineering work—can provide us. Consequently, when analyzing the contribution and resistance of *Trichoderma reesei,* I spoke of the specific activity, which is how biochemists defined the degradation capacity of the enzymes and also conceptualized its significance in the construction of ethanol production. I cannot imagine not using this language as a resource in my analysis. This language must, of course, be used in a versatile mutual interaction with other voices and points of view to attain a rich and credible account of the research object. A critical account is a multivoiced account that cannot be achieved by using any single privileged point of view or language alone.

The absence of dialogue implied by a symmetrical vocabulary also hampers the relevance and pragmatic validity of the research. For that reason I am interested in developing dialogue as an alternative (Miettinen, 1993). The elements of the idea of a research process as a dialogue have been presented by several scholars and research traditions. The founder of modern sociology of knowledge, Mannheim (1936) presented the idea, the monoperspectival picture in which objectivity could be replaced by a dialogue, "by juxtaposing the various points of views, each perspective may be recognized as such, and thereby a new level of objectivity attained" (pp. 296–297). The standpoint theory of knowledge maintains that objectivity can be optimized by dialogue between various points of view (Harding, 1993). The concept of dialogicity has also been developed by social psychologists (Marková & Poppa, 1990; Sampson, 1993), philosophers, and anthropologists (see, e.g., Megill, 1996) with the aim of finding an alternative to the monoperspectival view of objectivity. In the theory tradition of AT, the conceptualization of multivocality is inspired by the

[13] A tradition of monologism is connected in science studies to laboratory ethnography. It implied the principle of not becoming native and not accepting the language of the research object. Consequently, the voice of the researchers, oriented to a radical reformulation in sociology of science, dominates.

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work of Bakhtin. Multivoicedness is connected to the historical change of activities and social languages. The evolving, historically changing social languages are combined and used situationally by individuals connected to different activities (Bakhtin, 1981; Engeström, 1995).

In our studies on innovations, dialogue and intervention are consciously used in empirical research. In the study on the design and development of a neuromagnetometer (Neuromag), a device used in the detection of the neuromagnetic activity of the human cortex, we organized a user seminar with the firm that developed the device (Miettinen & Hasu, 1997). In the seminar, the users (brain and epilepsy surgery groups) articulated their needs concerning the use and development of the device. In addition, data and results from an ethnographic study of Neuromag measurements and of the organization of the Neuromag clinical services have been presented on several occasions to the developers and users of the device (Hasu, 1998). This modus operandi resembles what has been done in constructive technology assessment (Schot & Rip, 1998), in the user-centered and collaborative design approaches (Brun-Cotton & Wall, 1995). At the Center for Activity Theory and Developmental Work Research at the University of Helsinki, the forms and means of interventions, as well as the use of empirical data as a mirror, are being developed as an integral part of the research method (Engeström, 1991; Engeström, Virkkunen, Helle, Pihlaja, & Poikela, 1996). In the projects on research work and on innovations we have not decided, in advance, for such interventions. Instead, we have promised that whenever useful results and conceptualizations emerge, they will be brought to the communities to help them solve the vital problems of their activity. It seems that interventions keep stemming naturally from data collection and discussions with the practitioners (Miettinen & Hasu, 1997).

ACKNOWLEDGMENTS

The first version of this article was presented at the Actor Network Theory and After Conference, in Keele, England, July 1997. The comments presented at the conference and later received via the World Wide Web contributed to the rewriting of the article.

I thank Kari Toikka, Yrjö Engeström, and the anonymous commentators of *Mind, Culture, and Activity* for important comments and suggestions.

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