A SOCIO-COGNITIVE MODEL OF TECHNOLOGY EVOLUTION: THE CASE OF COCHLEAR IMPLANTS

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A SOCIO-COGNITIVE MODEL OF TECHNOLOGY EVOLUTION: THE CASE OF COCHLEAR IMPLANTS

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This paper examines the social and cognitive processes that unfold over time as a technology develops. Our model focuses on the relationship between the beliefs researchers hold about what is and is not technically feasible, the technological artifacts they create, and the routines they use for evaluating how well their artifacts meet with their prior expectations.

The historical development of cochlear implants serves as an illustration of the model. The evidence suggests that there is a reciprocal interaction between beliefs, artifacts, and routines that gives rise to two cyclical processes. One is a process of inversion at the micro-level of individual cognition wherein evaluation routines designed to judge specific artifacts begin reinforcing researchers' beliefs. Once evaluation routines become the basis for constructing individual reality, technological claims are perceived as relevant only to those who employ the same routines while appearing as noise to those who employ different routines. The other is a process of institutionalization at the macro-level of shared cognition. By institutionalization we mean the development of a common set of evaluation routines that can be applied to all technological paths. Commonly accepted evaluation routines represent a shared reality that strongly shapes the direction of future technological change.

The micro- and macro-level processes that shape individual and shared realities create a paradox. In order to succeed in the competitive struggle among researchers pursuing different technological paths, individuals create their own realities which then become self-reinforcing. To the degree in which they are successful in fostering their individual reality, however, researchers can become less adroit in their ability to embrace the emerging shared reality when it does not match their own. How well this paradox is managed can profoundly influence who emerges as the victor or the vanquished during the genesis of a technology.

KEYWORDS: Technology evolution; cognition; social construction; institutionalization; path creation.

Introduction

Among organization scholars there is a growing interest in the technological wellspring—and with good reason. Technological change can permeate all spheres of human activity, but no where are the effects of such change more discernible than with industry. New technologies can dramatically alter the competitive landscape, and by doing so, shake the foundation of the largest and most formidable firm, while bolstering the entrepreneurial dream of an individual who possess little more than the power of an idea. It is precisely this creative and destructive duality first noted by Schumpeter (1975) that gives technology its allure.

Previous attempts to understand technological change show how even the simplest of questions can become elusive: for example, *how do new technologies emerge?* While cursory observations into this question may suggest a linear progression from the conception of an idea to its commercial application, a more probing examination exposes a complex web of interactions between those who develop the technology, the physical artifacts they create, and the institutional environments they foster.

By scrutinizing one or more of these interactions, several different perspectives on technological change have been proposed.

One perspective examines the macro-level processes that can only be appreciated through the careful examination of the long-term struggle for survival among organizations. It is suggested that a new technology's emergence can be explained in terms of its capacity to diminish or enhance the value of a firm's existing human and capital investment (Abernathy and Clark, 1985; Tushman and Anderson, 1986). Technologies that diminish existing competencies are more likely to be introduced by newly created firms, while technologies that enhance existing competencies are more likely to be introduced by established firms. Thus, understanding the characteristics of a technology can help to explain whether a firm will embrace it or avoid it, and consequently, the likelihood that its emergence will cause a major disruption within an industry.

Another approach is to examine the micro-level dynamics of technological emergence. Historians have examined how a combination of individuals and events lead to the creation of alternative technological paths (Rosenberg, 1982; David, 1985; Arthur, 1988). In a similar vein, other scholars have examined how individuals create the institutional environment that shapes a technology's emergence (Barley, 1986; Weick, 1990). The "institutional" perspective has given rise to the notion that technological development is a co-evolutionary phenomenon, wherein there is a continual and reciprocal interaction between a technology and its environment (Rosenkopf and Tushman, 1993; Van de Ven and Garud, 1993). The co-evolutionary perspective provides an appreciation of the view that, when studied over time, the environment is both medium and outcome of the reproduction of technological practices (Giddens, 1979). The environment constrains as well as enables the development of a new technology a co-evolutionary fashion.

The co-evolutionary perspective underscores that technological development must be studied contemporaneously. We cannot fully understand the emergence of technology by means of assessments after the fact (Bijker, Hughes and Pinch, 1987; Latour, 1987). Indeed, when we observe technology-in-the-making, there is very little about the process of technological change that is obvious: it involves the "constant negotiation and renegotiation among and between groups shaping the technology" (Bijker, et al., 1987: 13). Therefore, it is important to closely follow researchers in order to understand how their negotiations influence what form technology will or will not take (Latour, 1987).

The view that technology is socially constructed stops short of asking how it is that individuals create a new technology with nothing else but the sheer strength of their ideas and beliefs. However, as Usher (1954) suggests, it may be important to scrutinize the cognitive roots of a technology to understand its subsequent development. Thus, while previous investigations have pointed to how the socially negotiated order of institutional environments directs technological change, we suggest that, it may also be useful to examine the negotiated order of beliefs themselves. Beliefs are the generative forces that set in motion *path-creation* processes—that is, the initial conception and enactment of technological artifacts and evaluation routines when nothing else exists but beliefs about what is or is not feasible.

Much can be learned from the literature on social and organizational cognition (e.g., Bateson, 1972; Berger and Luckmann, 1967; Neisser, 1976; Weick, 1979).

From the point-of-view of cognitive theory, reality is selectively perceived, cognitively rearranged, and interpersonally negotiated. At the extreme, social order has no existence independent of its members. Technology in the abstract resides in the minds of individuals, and therefore, can be understood more clearly through cognitive variables and decision premises than through behavior (Weick, 1990).

In this paper we seek to bridge the gap between the social and the cognitive processes that eventually become manifest in the form of technological artifacts. We propose a socio-cognitive model of technology evolution, which we illustrate with data on the development of cochlear implants—a surgically implanted electronic device that provides the profoundly deaf with a sensation of sound. While previous studies of cochlear implants (Garud and Van de Ven, 1987; Van de Ven and Garud, 1993) have examined the social creation of the institutional environment, in the present study, we show how the interaction between beliefs, artifacts and evaluation routines leads to the creation of alternative technological paths. In contrast to conventional methods used to study intra-organizational cognitive structures, we use interpretive methods to present evidence on the inter-organizational belief system—that is, the social-cognitive structure of a technological field.

Socio-Cognitive Model of Technology

The foundation of the socio-cognitive model we propose rests on three basic definitions of technology: technology as beliefs, artifacts, and evaluation routines. The first definition of technology is based on its representation as knowledge (Rosenberg, 1982; Laudan, 1984; Layton, 1984). Technology as knowledge provides the critical connection with the cognitive theory literature, where cognition is defined as "the activity of knowing: the acquisition, organization, and use of knowledge" (Neisser, 1976:1). Defining technology as knowledge has important implications for how we comprehend technology-in-the-making because it conceivably includes not only what exists, but what individuals believe is possible. These beliefs may include the "rules of thumb" (Sahal, 1981) or "search heuristics" (Nelson and Winter, 1982) that researchers employ to address technological problems. At a deeper level, beliefs may include a mosaic of cause-and-effect relationships between different facets that might influence the technological outcomes (Huff, 1990). To understand the evolution of technology from this perspective requires an appreciation of how beliefs form over time.

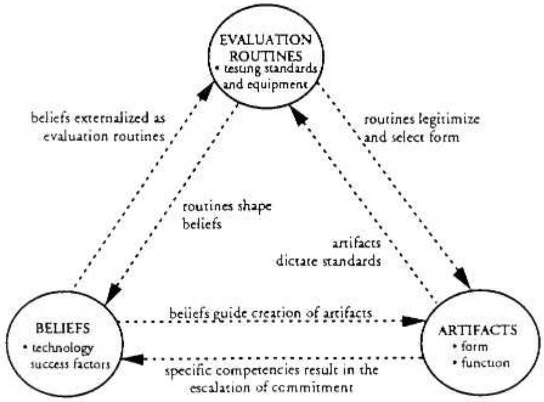
The second definition, physical artifacts, highlights the form and functional characteristics of a technology (Sahal 1981; Constant, 1987). Constituents of a technology's form may vary, but it usually implies attributes such as its dimensional shape and material of construction. Functional characteristics refer to how the technology is used. To understand the evolution of technology from this perspective requires an appreciation of not only how the form evolves but also what functions the technology serves over time.

Technology can also be defined in terms of a set of evaluation routines. For example, Jagtenberg (1983) suggests that technology manifests itself in certain practices that become institutionalized within a community of researchers. Such practices consist of testing routines and normative values that sustain and define the technology—what Constant (1987) calls "traditions of testability." The traditions of testability are inextricably linked to the instruments employed to generate the facts that are required to evaluate the technology (Latour and Woolgar, 1979). To understand the evolution of technology from this perspective requires an appreciation of how these evaluation routines emerge over time.

Each definition in our model highlights a unique, and therefore necessary, aspect of the process of technological development. In our approach, we draw on Neisser's (1976) cognitive theory of perceptual cycles, which consists of interactions between schema, perceptions and objects. Neisser defines a schema as an organization of experience that serves as an initial frame of reference for action and perception (Neisser, 1976:54). A schema directs an individual's perceptual explorations, which in turn leads to a selective sampling of the object, which in turn results in a modification of the schema. In this manner, the perceptual cycle revolves between schema, perceptual exploration and objects. Parallel with Neisser's model, we propose a "technology cycle" linking researchers' beliefs, the artifacts they create, and the evaluation routines they foster (see Figure 1). However, in contrast to Neisser's one-way interaction, we posit a reciprocal interaction between the three constituent constructs, whereby the genesis of a technology begins with the co-evolution of beliefs, artifacts and evaluation routines over time.

FIGURE 1

Socio-Cognitive Model of Technology Evolution



Reciprocal Interactions Between Beliefs and Artifacts

Weick (1979, 1990) suggests that technologies reside in two intersecting arenas—the mental and the physical (see also Kelly, 1963). At the intersection of these two arenas, is the idea of enactment where people "actively put things out there" (Weick, 1979: 165) in the form of physical artifacts. Physical artifacts put sense-making in motion. Individuals interpret artifacts in an abstract way in order to cope with the complexity involved (Weick, 1990). Artifacts are cognitively worked upon by categorizing them with reference to existing beliefs. At the same time, individuals interact with and constitute these artifacts thereby shaping their evolution in particular directions.

Thus, there is a reciprocal linkage between beliefs and artifacts. This reciprocal linkage is discussed by Dosi (1982) in terms of technological trajectories. Trajectories represent specific paths of technological change based on researchers' beliefs. Early on, during the development of a technology, researchers may hold divergent beliefs about "what is feasible or at least worth attempting" which leads them to pursue different paths (Nelson and Winter, 1982: 258-259). Because of the high degree of uncertainty involved (Anderson and Tushman, 1990), it is not possible to *ex ante* determine the success or failure of any particular technological path. Different researchers therefore "place their bets" on different paths.

Researchers develop specific technological competencies over time. These competencies accumulate in a path-dependent manner as earlier technological choices direct future options and solutions (Cohen and Levinthal, 1990; Arthur, 1988; David, 1985). As competencies become specialized, researchers find it increasingly difficult to redirect themselves to other paths. As a consequence, there are powerful incentives for a researcher to persist along a chosen path.

Reciprocal Interactions Between Beliefs and Evaluation Routines

Geertz (1973: 5) describes man "as an animal suspended in webs of significance he himself has spun" through the process of enactment and interpersonal negotiation (Weick, 1979). Similarly, Kelly (1963) suggests that individuals create visual templates which they attempt to fit over the realities of which the world is composed. These templates consist of constructs that enable individuals to validate knowledge and evaluate phenomena. Employing insights from gestalt psychology, Bateson (1972) argues that "individual validation" is required because we operate more easily in a universe in which our own psychological characteristics are externalized.

From this perspective, evaluation routines are an external manifestation of our beliefs and serve as second-order frames (Bateson, 1972: 187). Data inconsistent with an individual's evaluation routines are either ignored or appear as noise. Data consistent with evaluation routines are perceived as information and cognitively rearranged in a manner that reinforces an individual's beliefs. Given bounded rationality, this bracketing of perception occurs because individuals may be more interested in confirming their beliefs than in actively trying to disprove them (Weick, 1979). In this manner, an individual's beliefs are externalized, then objectified, and finally internalized (Berger and Luckmann, 1967). When this process occurs in groups, it may lead to multiple environments, with each subgroup enacting its' own