Working Paper Series

05/2006

Socio-technical dynamics underlying radical innovation: the case of Polaroid's SX-70 camera

Garud, R. and Munir, K.

CAMBRIDGE
Judge Business School

These papers are produced by Judge Business School, University of Cambridge. They are circulated for discussion purposes only. Their contents should be considered preliminary and are not to be quoted without the authors' permission.

Author contact details are as follows:

Raghu Garud	Kamal Munir
Stern School of Business	Judge Business School
New York University	University of Cambridge
rgarud@stern.nyu.edu	k.munir@jbs.cam.ac.uk

This paper was presented at the Academy of Management Annual Meeting 2004.

Please address enquiries about the series to:

Research Support Manager
Judge Business School
Trumpington Street
Cambridge CB2 1AG, UK
Tel: 01223 760546 Fax: 01223 339701
E-mail: research-support@jbs.cam.ac.uk

SOCIO-TECHNICAL DYNAMICS UNDERLYING RADICAL INNOVATION: THE CASE OF POLAROID'S SX-70 CAMERA*

Raghu Garud
New York University
40 West 4th St., 7-13
New York, NY 10012
(212) 998-0255

&

Kamal Munir
University of Cambridge
Judge Institute of Management
Cambridge, CB2 1AG
United Kingdom
+ 44 1223 337054

October 29, 2003

Keywords: Radical innovation, disruptive change, creative destruction, socio-technical dynamics.

---

* We are indebted to several people including Victor McElheny, Sam Liggero, Fara Faramozpour, Nasrin Rohani and Dave Laituri for their help in shaping our understanding of the micro processes involved in the emergence of Polaroid's SX-70 camera. We also thank Arun Kumaraswamy, Steve Maguire, Carliss Baldwin and Joe Porac for their insightful comments on earlier drafts. We thank Neha Bagchi for her editorial help. This paper has been presented at several forums including the Academy of Management Meetings 2003, Singapore Management University, Innovation Network, Boston 2003, Copenhagen Business School, Denmark, Entrepreneurship Conference at Seattle and Leverhulme Conference at the London Business School. We gratefully acknowledge the inputs of the many who offered their feedback at these forums. We are also grateful to Cambridge-MIT Institute and Leonard N Stern School, NYU for their financial support.

SOCIO-TECHNICAL DYNAMICS UNDERLYING RADICAL INNOVATION: THE CASE OF POLAROID'S SX-70 CAMERA

Abstract

This paper explores the socio-technical dynamics underlying radical innovation. Our study of the emergence of Polaroid's SX-70 camera design reveals that processes associated with radical innovations are neither evolutionary nor can they be completely pre-specified. Rather, radical innovation involves a process of interactive emergence wherein the technical architecture of a design co-evolves with its social architecture. Our exploration of the development of Polaroid's SX-70 camera reveals how the recombination of knowledge across the camera modules compromised embedded interests of the actors responsible for the various components. As a result, the integration of the physical elements of the camera led to a disintegration of Polaroid's existing social architecture.

An important facet of the modern economy is that industries are becoming increasingly systemic (Langlois & Roberetson, 1992). Many components, often spanning firms and industries, have to work together to provide functionality to customers. An equally important facet of the economy is the increasing frequency with which radical innovations are disrupting the functioning of existing technological systems (Christensen, 1997). Radical innovation is manifest by changes not only to the components of a technological system but also in the ways in which the components interact with one another (Henderson & Clark, 1990).

Radical innovation has the power to redraw industry boundaries, and, in the process, shake the foundations of even the largest of firms (Anderson & Tushman, 1990; Christensen, 1997; Schumpeter, 1950; Tripsas, 1997; Utterback, 1994). It is not surprising, therefore, that firms would like to be the architects of radical innovation (Leifer, McDermott, O'Connor, Peters, Rice & Veryzer, 2000). However, orchestrating radical innovation is fraught with difficulties. Not only do technical challenges abound, but also, there are challenges that arise from the need to coordinate social entities with strategic interests. Consequently, even firms that possess the necessary financial and technological resources to orchestrate radical innovation can lose their way.

What are the processes that unfold during periods of radical innovation? And what roles do firms play in shaping these processes? To address these questions, we build upon existing literature on the emergence of designs. Two contrasting perspectives are apparent (Alexander, 1964; Steadman, 1979). One is evolutionary wherein radical innovation is a random outcome. Embracing such a Darwinian perspective, Simon suggested that there is no need to evoke teleology to explain the emergence of designs noting that their evolution "is nothing more than survival of the fittest" (Simon, 1962: 203). In contrast, an engineering-design perspective emphasizes the roles that humans play in their abilities to pre-specify and shape the emergence of designs. In this view, humans have the ability to create the 'best' designs by taking into consideration engineering issues on form and function (Petroski, 1996) as well as the transaction costs associated with any design (Baldwin & Clark, 2002).

Whereas these perspectives have offered considerable insights into the emergence of designs, both embrace an under-socialized view. While the first discounts teleology (Simon 1962:203), the second tends to overlook the historical contingencies involved including the socio-political dynamics that characterize innovation (Thomas, 1994). We find these omissions to be problematic because technical architectures are always embedded in social architectures (Bijker, 1995; Hargadon & Douglas, 2001; Latour, 1991; MacKenzie & Wajcman, 1985). Consequently, any re-arrangement of the technical architecture is bound to create tensions in the social architecture (Hargadon & Douglas, 2001). Indeed, in their quest to achieve a radical innovation, firms may even alienate erstwhile collaborators, at worst turning them into competitors.

Joint consideration of technical and social architectures reveals that radical innovation is neither a random outcome nor one that can be completely pre-specified. New designs emerge through an interactive process wherein technical specifications co-emerge with social and economic interests of the parties involved. At any stage of emergence, the co-emergence of social and technical architectures offers participants new opportunities even as others are foreclosed. Architectures, from this perspective, are both cause and consequence of the dynamics that unfold and any account of the emergence of designs has to pay symmetrical attention to both the technical and social architectures.

We explicate these dynamics by examining the emergence of the social and technical architectures surrounding the emergence of Polaroid's SX-70 camera. Introduced in 1972, the SX-70 was hailed as one of the greatest technological accomplishments in the history of the industry. The design involved the unprecedented step of incorporating the camera battery into a highly innovative ‘self-developing’ film that ‘transformed’ into prints, while generating no waste. The production of the SX-70 was thought to be at a critical juncture in the evolution of photographic technology. The new camera received widespread publicity in the popular press and even appeared on the covers of *Life* and *Time* magazines.

However, in the creation of this design, Polaroid was fundamentally transformed in unexpected ways. Decisions taken on technical and economic grounds ended up unleashing social dynamics that left Polaroid without the support of its traditional supplier network. The SX-70 even led to the creation of counter-forces. For instance, before the introduction of the SX-70, Kodak and Polaroid had enjoyed a collaborative relationship. The SX-70 dramatically changed this relationship, and, in the end, left Polaroid and Kodak as rivals.

To understand the sequence of events that unfolded, we first develop a perspective of designs as ensembles of parts embodying actors’ interests. We then show how an appreciation of interests embedded in designs draws attention to the tensions that lie at the interface of firm interactions. These tensions, we suggest, set the seeds for radical innovations to unfold. We then employ this perspective to examine the dynamics of the SX-70 innovation. From this study, we develop several propositions culminating in insights on the complexities of radical innovation.

PERSPECTIVES ON DESIGNS

We begin our discussion on designs with Simon’s (1962) seminal contributions on decomposability. Decomposability refers to system partitioning in such a way that the interactions of elements within a sub-systems are greater than the interactions between them. Such partitioning implies cognitive “black boxing.” At any point in time, those associated with a sub-system need not know the workings of others. Instead, they need only know what is required to complete the specific sub-system that they are working on.

The concept of decomposability has generated a lot of attention from those interested in modularity (cf. Baldwin & Clark, 2000; Ethiraj & Levinthal, 2002; Galunic & Eisenhardt, 2001; Garud & Kumaraswamy, 1995; Henderson & Clark, 1990; Sanchez & Mahoney 1996; Schilling, 2000). Complex systems can be decomposed into modules in such a way that each module becomes a black box, possessing details required for its functioning, but hiding these details from other interdependent modules. With such systems, it is possible to distribute tasks across a number of social groups within and across firms, with each group possessing a different set of competencies.

Holding any design together is an overall architecture (Clark, 1985; Henderson & Clark, 1990; Baldwin & Clark, 2000; Ulrich & Eppinger, 2000). The architecture prescribes the relationships between the various parts, their inputs and outputs, interface specifications, measurement approaches to ensure conformance and the like (Baldwin & Clark, 2000). As Clark (1985:241) suggested, the architecture involves "a process of analysis, of identifying the components of the form, the major systems and sub-systems, and then grouping them in different ways to illuminate their interrelations."

The architecture also defines a system 'hierarchy', a set of superior and subordinate relationships between black-boxed elements (Alexander, 1964; Simon, 1962). In this regard, Clark (1985) suggested, "in the case of design, a hierarchy of concept seems to be inherent in physical objects" and emphasized, "one parameter sits at the apex, and is particularly trenchant in its impact on other aspects of the domain. Such concepts are 'central' or 'core' in the sense that the choices they represent dominate all others within the domain" (Clark, 1985:241-243). Indeed, core components are connected to many others as compared to peripheral ones (cf. Griffith, 1999; Tushman & Murmann, 1998).

Evolutionary perspective

These observations have served as the basis for the articulation of several perspectives on the emergence of designs. One perspective is evolutionary. For instance, Simon (1962) noted that the principle of decomposition is a universal property of all systems and that modular forms possess evolutionary benefits over integral ones. Indeed, Simon argued "the theory assumes no teleological mechanism. The complex forms can arise from the simple ones by purely *random* processes […and…] the existence of stable intermediate forms exercises a powerful effect on the evolution of complex forms" (Simon, 1962:203, italics added).

Simon's perspective is consistent with Alexander's (1964:46-54) description of how design rules are transmitted across generations "unselfconsciously." Such a process, Alexander reflected, has a "certain built-in fixity – patterns of myth, tradition, and taboo which resist willful change. Form-builders will only introduce changes under strong compulsion where there are powerful (and obvious) irritations in the existing forms, which demand correction" (Alexander, 1964: 48).

The evolutionary perspective is evident in the description of the emergence of the stereo and computer systems that Langlois and Robertson (1992) have offered. Enumerating both supply and demand side benefits from modularity, Langlois and Robertson (1992: 311-312) pointed out that "in both cases [stereo and computer systems], first of all, the industry adopted a modular structure with a common standard of compatibility rather than a structure of competing prepackaged entities… Indeed, one might speculate in general that modular systems are likely to take on greater importance in the future."

Engineering design perspective

This evolutionary perspective on the emergence of designs has not been left unchallenged. For instance, Steadman (1979) in his critique suggested that, if we were to adopt a purely evolutionary perspective, then:

> "the individual designer or craftsman tends to fade away, and even disappears altogether....The real effective 'designer', in this view, is the 'selective' process, which is constituted by the testing of the object in practical terms when it is put into use….the designer has only an error-correcting function; he spots failures in certain versions of the design of some artifact, and copies those other versions in which the failure does not occur. Alternatively, he may detect a shortcoming in a design, and make changes *randomly* in that particular feature, in the hope of hitting by chance upon some appropriate alteration." (Steadman, 1979: 188-189, Italics added for emphasis)

Clearly, random outcomes are unacceptable to those embracing an engineering design perspective. Thus, comparing technological systems with biological ones, Ziman (2000) pointed out that "the most obvious difference is that novel artifacts are not generated randomly: they are almost always the products of conscious *design*" (Ziman, 2000: 5). Henry Petroski, who has written extensively on designs from an engineering perspective, shared this view. He wrote:

> "If we were content with everything around us, we would have no conception of improvement and the worlds would be a static place. Indeed, it has been held by some engineers that by not striving for more and more economical construction, the engineering profession would be irresponsibly appropriating limited resources to over design everything from beverage cans to bridges." (Petroski, 1996:6)

Recent application of transaction cost economics to the design of efficient architectures extends this engineering design perspective (Baldwin & Clark, 2002; Garud & Kumaraswamy, 1995; Langlois, 2003). Baldwin and Clark (2002), for instance, have suggested that modular designs facilitate a division of labor that is important to alleviate cognitive limitations. Numerous flows, or transfers of material, energy and information, underlie the functioning of any system. Baldwin and Clark suggested that interfaces should be located within the system, where standardizing, counting and compensating for what is being transferred is relatively easy and inexpensive, and the common information needed on both sides of the transaction is minimized, thereby maximizing the division of cognitive labor. In other words, social partitions ought to be created where the 'mundane' transaction costs (Williamson, 1985; Baldwin & Clark, 2002) of creating a transactional interface (the costs of defining what is to be transferred, of counting the transfers, and of valuing and paying for the individual transfers) are at a minimum.

Baldwin and Clark's (2002) perspective stands in contrast to Simon's (1962). Whereas Simon wanted to offer a perspective that assumed no teleological mechanism (Simon 1962:203), Baldwin and Clark's design perspective emphasized the role of humans in pre-designing architectures to reduce transaction costs. As Baldwin and Clark stated: "Our goal is to explain the location of transactions (and contracts) in a system of production. Systems of production are engineered systems, and where to place "transactions" is one of the basic engineering problems that the designers of such systems face" (Baldwin & Clark, 2002:3-4).

The social embeddedness of designs

Invoking social relationships that are embedded in technological designs adds a critical new dimension to the perspectives presented so far (Garud & Rappa, 1994; Hargadon & Douglas, 2001). Social constructivists (Hughes, 1983; Bijker, 1995; Bijker and Law, 1992) have long considered the emergence of technological systems to be intimately intertwined with the construction of social arrangements. Rather than view technological designs as outcomes of pre-designed or evolutionary processes, social constructivists regard designs as a cause and consequence of social processes involving the complex interplay of professional, technical, economic, and political factors.

This perspective suggests that organizational relationships and hierarchies become embedded in designs. Tracy Kidder vividly illustrated this in her book, "Soul of a new machine" (1981). Kidder described the experiences of Tom West, a V.P. at Data General who, after sneaking into a competitor's (DEC) facility at night, and opening up their complex black box (DEC's new VAX computers) concluded "VAX embodied flaws in DEC's corporate organization. The machine expressed that phenomenally successful company's cautious, bureaucratic style" (Kidder, 1981:36).

Economic interests of various stakeholders are similarly embedded in designs (Callon, 1986; Garud & Karnøe, 2002). During the emergence of electricity generation systems, for instance, Hughes (1983) described how the interests of several stakeholders were embedded in the network of power generation. Among the many who were involved included manufacturers of physical artifacts such as the turbo generators, transformers, and transmission lines in electric light and power systems, as well as organizations such as manufacturing firms, utility companies, and investment banks (Hughes 1983).

These sentiments are reflected in Ziman's (2000) arguments as to why we should consider the interests of involved actors in gaining a deeper understanding of the emergence of designs. He stated: "Many intangible features of the surrounding culture – for example, military techniques and commercial practices – change over time, hand in hand with the change in the artifacts to which they are connected. Thus, if technological entities (in the narrow sense) are deemed to 'evolve', then this interpretation must surely extend to the social entities with which they interact" (Ziman, 2000: 8)

Embedded interests keep designs alive (Gilfillan, 1935; Hargadon & Douglas, 2001; Latour, 1991). Even the most proprietary of products, such as the Microsoft Operating System, requires supporting stakeholders such as application developers whose economic interest are directly or indirectly aligned with Microsoft's. Similarly, the use of cameras for photography benefits camera companies film manufacturers, photofinishers, retailers and possibly a host of accessory manufacturers. Their presence, in turn, ensures the availability of inexpensive films, photo finishing services and camera repair facilities, thereby providing us with an opportunity to use cameras with ease.

In sum, far from being just an agglomeration of physical parts, designs are, in fact, socio-technical ensembles (Bijker, 1995). In his explication of this perspective, Bijker suggested, "The technical is socially constructed, and the social is technically constructed. All stable ensembles are bound together as much by the technical as by the social" (Bijker, 1995, p. 273-274). Indeed, the activities of agents are "embedded in larger technological regimes, which consist not only of a set of opportunities but also of a structure of constrains in the form of established practice, supplier-user relationships and consumption patterns" (Kemp, Schot & Hoogma, 1998:181-182).

Consequently, any change in the physical arrangements unleashes social forces that shape the emergence of designs. As Hargadon and Douglas (2001:476) suggested, "when innovations meet institutions, two social forces collide, one accounting of the stability of the social system and the other for change." In the process, at any stage of emergence, new possibilities open up even as others close. Confronting such emergent possibilities, stakeholders engage in a fresh round of calculations. As Steadman (1979:204) pointed out: "It is very common for both designer and client to revise their original goals and intentions in the light of information, which the process of design itself produces. What is very certain is that, within the problem considered as a whole, the separate 'environments' of each sub-problem will be continually altering, and the boundaries between problems moved, as the various aspects of the design are worked on."

New designs, then, can neither be completely pre-specified, nor is their emergence evolutionary. Instead, the emergence of physical and social partitions, including their hierarchical status, is an interactive process involving not only the physics of designs but also the embedded interests of involved actors. It is this interactive process that we wish to examine empirically. Specifically, we want to understand processes whereby the social and physical architectures co-emerge paying special attention to the role of human agency involved. The design and manufacture of Polaroid's SX-70 camera, a product considered to be one of the most remarkable designs in recent history, provides the context within which we explore these issues.

RESEARCH SITE AND METHODS

An exploration of the dynamics of radical innovations requires us to take a process perspective (Mohr, 1982), which typically involves longitudinal analysis (Van de Ven, 1992). Consequently, in studying the genesis of the SX-70, we relied upon the accounts of many who wrote about the emergence of SX-70 based on their real-time experiences. Polaroid's initiative at redefining photography with its SX-70 camera attracted the attention of journalists, historians and insiders who, in real-time, wrote about the events surrounding the emergence of the SX-70 camera. There is no dearth of material about what happened, who was involved and the context within which events unfolded. The descriptions, although from difference sources, are mutually confirming, thereby generating confidence in the quality and depth of the data from which we arrived at our inferences.

Altogether we have read and analyzed close to a hundred or so periodicals, many obtained from online databases such as PROQUEST and from periodicals maintained by the New York Public Library. We also read three books devoted to the SX-70 camera, Edwin Land and Polaroid.[1] The author of one of these books, Victor McElheny was on sabbatical from the Massachusetts Institute of Technology in the early 1970s to study the development of the SX-70. We were able to contact him and, over the course of several interviews, benefited immensely from his first-hand knowledge of the entire process.

---

[1] These included, Victor McElheny's Insisting on the impossible: The life of Edwin Land (1998), Mark Olshaker's The instant image: Edwin Land and the Polaroid experience (1978), and Peter Wensberg's Land's Polaroid: A company and the man who invented it (1987).

We were fortunate to obtain the rights to use Polaroid's archives, which provided us access to several thousand internal memos, old analysts' reports, in-house publications, press cuttings and other similar material. This effort yielded insights on the micro details that had not been reported in the periodicals and books. Finally, we interviewed several high-level executives at Polaroid, many of whom had first-hand experience of the SX-70 innovation.

To analyze the data, we constructed a database that contained the events that had unfolded, the sources from which we had identified these events and our interpretations (Miles and Huberman, 1984; Glaser and Strauss, 1967). We tracked changes to the technical and social architectures before, during and after the emergence of the SX-70 design. As we were interested in human agency, we paid particular attention to the motivations and aspirations of the actors involved.

Consistent with a process perspective, we considered each event as an important occurrence within a larger flow of events (Campbell, 1975; March, Sproull & Tamuz, 1991; Van de Ven, 1992). This 'contextualized' approach to the interpretation of events helped us generate a deep and consistent understanding of the unfolding processes. We actively abandoned or modified tentative hypotheses and retained those that had greater validity with the stream of data on Polaroid.

The process of interpretation itself was emergent and iterative between data and theoretical constructs until a stage of theoretical saturation was reached (Glaser and Strauss, 1967). For most part, interpretations of the events were very consistent between the two researchers involved. There were occasions when we found that additional data were required. We contacted industry experts, who were always ready to help. Our task was simplified as we had already interviewed several of the industry participants earlier to gather information pertaining to the case.

Eventually, we wrote a descriptive case that we shared with industry experts. Their confirmation of the accuracy and depth of the case was welcome feedback, and the analysis that we present here is based on this case. In addition to the description, we also offer our interpretation of the incidents that transpired. In doing so, we explicate our theoretical framework and, at the same time, generate additional insights that we report in our discussion.

THE CASE OF POLAROID'S SX-70

The remarkable saga of the SX-70 first came to public attention in 1968 when Polaroid and Kodak executives met in 1957 to discuss improvements and ideas to the Instant film negative that Polaroid had outsourced to Kodak (see Table 1 for a chronology of key events). Whereas such meetings had been routine in the past, in this particular meeting, held in April 1968, Polaroid executives casually described a new color film that they had been working on for a while. Six months later, Polaroid's CEO, Edwin Land, showed Kodak's VP of Research some photographs made on the new material. Peter Wensberg, then Polaroid's Director for Marketing, reported:

> "Kodak was stunned. A year later it canceled the 1957 agreement, which called for cooperative development….the termination of the color negative agreement sent a clear signal that *war* had been declared in the field of instant photography." (Wensberg, 1987:172-173)

-- Table 1 here --

The 'war' that Wensberg alludes to in the above quotation had its origins in Polaroid's decision to undertake a massive technological initiative to revolutionize Instant photography, potentially making its own existing technology obsolete. This initiative aimed at producing the remarkable SX-70 camera and film system (the prints that Land showed Kodak in 1968 were an interim result of this effort) was widely considered to be an enormous technological success. The system took about eight years in preparation, costing more than $500 million (Cordtz, 1974;

Tripsas & Gavetti, 2000). When the early models came out, analysts were enthralled by the giant leaps that Polaroid had made in Instant technology. Fortune magazine called the production of the SX-70 "one of the most remarkable accomplishments in industrial history" (Cordtz, 1974: 85), with pictures of Land with the SX-70 appearing on the covers of both Time and Life magazines.

While garnering accolades from all corners, the SX-70 dramatically transformed Polaroid's socio-technical ensemble, severely affecting its relationships with vendors, competitors, customers and other institutional stakeholders. The 'war' with Kodak, for instance, was one of the many unwanted outcomes of this technological revolution, with dire consequences for Polaroid's competitive position in the industry.

Polaroid and pre SX-70 technology

Polaroid Corporation, founded in 1937 by Edwin Land, is perhaps best known for inventing Instant imaging technology. With Instant photography, Polaroid managed to automate and enclose an entire development laboratory in a small, hand-held camera. Despite the poor picture quality, the inconvenience of having to peel the negative apart from the positive and the litter that was created in the process, the Land camera, introduced in 1947 was an instant hit, propelling Polaroid's sales from $6.7 million in 1949 to nearly $550 million twenty years later. In these twenty years, every dollar invested in Polaroid common stock grew to over $500 dollars.

With any Polaroid Instant camera, a user inserted a film pack of 10 pictures into the camera. With the press of a button, an image was exposed onto a roll of negative photographic paper that met up with a roll of positive paper. As the negative and positive were pulled through rollers together and out of the camera body, a chemical reagent was spread evenly through the middle of the positive-negative "sandwich." This allowed the image to develop and transfer onto the positive. Once out of the camera, the sandwich was clipped from the respective rolls by a pair of knife blades and peeled apart after allowing some time for the transfer of the image to take place from negative (which was covered by an opaque layer to prevent light from entering) to positive. Eventually, the negative was rendered useless and had to be disposed of (adapted from Olshaker, 1978).

Polaroid's socio-technical ensemble Prior to the SX-70, Polaroid was responsible only for making the positive, the pod containing the chemical reagent and some of the final assembly. Principal camera manufacturing was outsourced mostly to U.S. Time Corp. and Bell and Howell Corp. The camera operated on standard batteries, easily available at any store. Kodak produced color negatives for Polaroid's Instant films, with the former receiving $1 for every film sold (Brand, 1972). Kodak reportedly made an 80% pretax profit on these sales (Time, 1972: 86). In this way, the interests of several stakeholders were embodied in Polaroid's socio-technical ensemble.

These interests both enabled and constrained the emergence of the system. For example, by agreeing to provide negatives to Polaroid, which, at that stage, had neither the capital, nor other resources to build a negative manufacturing plant, Kodak made it possible for Polaroid to offer its cameras. On the other hand, Polaroid had to adapt its original design to suit Kodak's manufacturing facilities and, subsequently was restricted in the number of changes that it could make to the design of the film depending upon Kodak's willingness to make changes. In this way, Kodak constrained the evolution of Polaroid's design (McElheny, 2002). These constraints blocked the path of several potential innovative solutions to the complexities that a user faced when using Polaroid cameras.

Figures 1a and 1b depict the "decomposition" of the camera-film system before and after the advent of the SX-70 camera. Although several other components and transactions were involved, we have simplified the diagram by focusing on the relevant transactions and firms involved. As Figure 1a depicts, Polaroid made the positive, Kodak the negative and the standard battery was manufactured and supplied by any of a number of battery manufacturers.

-- Figure 1a and 1b here –

Although the relationship between Polaroid and Kodak was mutually beneficial, Kodak's reluctance to make any changes in the negative generated tensions. Moreover, both companies confronted strategic uncertainty. As McElheny (1998: 351) described:

> "For Kodak, continuing to supply negative to Polaroid meant increased investment to serve a single customer – which could always decide to meet its own needs for the technology it had developed. What would happen to Kodak's investment then? Kodak wanted an economic use for its instant negative production if Polaroid decided to make its own, and so it extracted from Polaroid a license to enter the peel-apart business. As for Polaroid, it was never certain when Kodak would agree to alter the process to accommodate Polaroid's improvements or to enlarge total production." (McElheny, 1998: 351)

SX-70 specifications Despite the enormous success of cameras and film based on the then existing technology, Polaroid started work on a revolutionary new film and camera system in the mid-1960s. The new camera, code-named SX-70 (Figure 2) was to be fully automatic in addition to being a single-lens-reflex (SLR) camera that was small enough to fit into a pocket or a purse (Merry, 1984).[2] The overall vision for this revolutionary camera stood out in its effort to make it into a total "black-box" for Polaroid's customers. McElheny (1998:353) captured these efforts succinctly when he pointed out, "as in so many systems of our age of technology, complexity was harnessed to achieve simplicity for the user." Specifically, there was to be:

> *"No* pulling the picture packet out of the camera, *no* timing the development process, *no* peeling apart of the negative and positive results, *no* waste material to dispose of, *no* coating of the print, *no* print mount to attach, *no* chance for double exposure, *no* chance to forget to remove the film cover sheet and spoil a picture, *no* exposure settings to make, *no* flash settings to remember, *no* batteries to replace." (Polaroid Annual Report, 1972; italics added)

[2] Single-lens-reflex (SLR) means that the user views the subject through the lens, rather than the viewfinder.

-- Figure 2 here --

Thus, rather than prescribe what would be, the specifications proscribed what must not be. Such an approach clarified the magnitude of the technological challenge involved while leaving room for the emergence of both technical and social architectures. Sheldon Buckler, Vice President of Research at Polaroid maintained (quoted by Cordtz, 1974:87):

> "The way the camera was defined, something like that had to exist. But the problem was not just that it didn't yet exist, but that we didn't know the phenomenon that would give it the foundation to come into existence."

From the very beginning, then, the SX-70 design was neither pre-specified nor was its emergence left to random chance. Interactive emergence based on an overall vision that shaped but did not pre-determine was critical in the case of the SX-70 camera where "every piece pushe(d) the others" (Buckler about the SX-70 in McElheny, 1998: 354). In the case of the SX-70 camera, for instance, many changes occurred, two of which had to do with the integration of the positive and the negative into one integral film pod and the incorporation of the battery into this pod.

Polaroid understood the need for informal transfers required to create the integral film and, consistent with Baldwin and Clark's (2002) analysis, decided to draw the manufacturing of the negative into a transaction-free zone within Polaroid. However, the battery was perceived by Polaroid to be a 'peripheral' component, lower down in the technical hierarchy, and was thus contracted out to ESB Inc. (later Exide Corp.). These decisions, largely motivated by technical challenges, had unexpected social repercussions, eventually resulting in the redrawing of Polaroid's socio-technical ensemble.

From Peel-apart to Integral film

Polaroid's decision to eliminate the need to pull apart negative and positive implied that the negative and positive would always remain an integral part of a card-size package (the picture that came out of the camera). Such a design meant greater interdependencies between the negative and positive, most of which were poorly understood at that stage. Working these interdependencies out further implied complex transfers of energy, materials and information across the interface with Kodak, which made the negative (Figure 1a).

Complexities and interdependencies The challenge posed by the integral film can be understood by realizing that, because of the small size of the camera, the film had to develop in bright light *after* it was ejected from the camera (McElheny, 1998). Since images cannot possibly develop in bright light, something in the film had to act as a curtain, until the image developed, and then vanish. What that 'something' was, nobody knew at that time.

The problem was complex since such a chemical curtain or 'opacifier,' if it existed at all, would have to exist in a "relationship of mutual dependence" with other elements of the film (Polaroid Annual Report, 1974). As Land put it, "the negative component, for all of its mechanical sophistication, is …one member of a three-fold partnership, the other two partners being the viscous reagent and the image-receiving sheet" (Polaroid Annual Report, 1974).

Figure 3 depicts a cross-sectional view of the SX-70 film. A small fraction of the thickness of a pencil line, the SX-70 film was composed of 13 principal layers, with the behavior of each layer controlled to extremely high degrees of precision.

-- Figure 3 here --

Experimentation with various possible opacifiers involved all three elements of the film, with chemical reactions between the positive, reagents, opacifying dye, dye-developers and moralized dyes often leading to unanticipated problems. The pre-SX-70 film structure already contained many interdependencies even across the artificially "nearly decomposed" positive-negative interface. With the integration of the positive and negative, these interdependencies were enhanced. As Land pointed out, "The new film process required an elaborate chemical balancing act performed by dozens of ingredients. [These ingredients] migrate, react, dissolve, oxidize, reduce and combine with precision—then all activity ceases when the picture is finished" (Reinhold, 1972:47). As McElheny wrote:

> "The 'integral" film' of the SX-70 posed new stabilization problems because it permanently held both positive and negative. [In the SX-70 integral film] the interactions between negative and positive became far subtler and more complex…Land's teams had to 'play around' with the negative design in the decade of designing it." (McElheny, 2002)

Apart from the complications and uncertainties involved in the design phase, a second set of interdependencies – between design and manufacturing – was also introduced with the SX-70. As McElheny (1998: 380) pointed out, "the new system was not emerging in the neat progression of idea, early research, pilot phase, manufacturing development, and then manufacturing." Emergence of the SX-70 camera required simultaneous efforts on several fronts. Indeed, time pressures to meet the launch deadlines in 1972 intensified the need for simultaneity across different stages. Polaroid could not possibly afford to first finish the design of the negative and then ask Kodak to set up a manufacturing facility for it. All steps during design of the film had to pass through a manufacturing screen. For that, Polaroid required knowledge of manufacturing that only Kodak possessed.

Given this situation, the only way Polaroid could meet its deadline was to ensure that design and manufacturing proceeded in parallel. Given the uncertainties surrounding the final design, knowledge of manufacturing negatives was constantly needed to reach practical solutions to new problems. According to Dr. Sam Liggero, an ex-Vice President of Polaroid:

> "If the existing agreement with Kodak had continued, it is inconceivable that Polaroid would have been able to achieve the goals set for SX-70. To begin with, Polaroid would have had to work without any knowledge of manufacturing. It would thus need to check with Kodak at every stage, perhaps several times a day, whether a particular solution was feasible, both in terms of theoretical possibility and Kodak's willingness to do it." (Liggero, 2002)

Breaking apart from Kodak Polaroid announced in 1969 that, while Kodak could go on manufacturing negatives for its existing film, Polaroid would manufacture its own negatives for the SX-70 (Figure 1b). Given the uncertainties surrounding the final shape of the interface between the negative and the other two elements of the film, Polaroid decided to design and manufacture the negative as well— pulling the negative into a 'transaction-free' zone (Baldwin and Clark, 2002).

This decision is of particular interest given the potential benefits of modularity (see Sanchez 1996). Despite these potential benefits, Polaroid had always wanted to know more (Brusoni, Prencipe & Pavitt, 2001) about negative manufacturing than was necessary because it felt constrained by the division depicted in Figure 1a. Kodak, far from showing any flexibility, was completely unwilling to engage in transfers across its contractual interface with Polaroid. Due to this inflexibility, Polaroid spent more than $60 million to develop its own negative plant (Olshaker, 1978; McElheny, 1998). Polaroid argued that designing and manufacturing its own negative would make it possible to negotiate the complex interdependencies introduced by the integration among the various layers of the film, enabling it to alter all aspects of the film freely. Now Polaroid was free to introduce running changes, such as more brilliant colors, an anti-glare coating, and faster processing times, which it did (McElheny, 2002).

The elimination of Kodak from Polaroid's socio-technical ensemble (Figure 1b) paved the way for Polaroid to create a radical change in its design. At the same time, this move resulted in destabilizing Polaroid's existing socio-technical ensemble. Once united in a mutually beneficial relationship[3], Kodak and Polaroid became intense rivals. Almost immediately after Polaroid's announcement, Kodak declared that it was not going to manufacture negatives for

---

[3] In a New York Times article, McElheny reported that the cooperation between Kodak and Polaroid "appeared so close that in 1971 the Justice Department conducted a low-key antitrust investigation" (McElheny, 1976: pp.77).

Polaroid's existing line of film (pre-SX) anymore (Siekman, 1970). While the existing agreement between the two companies allowed Kodak to enter the Instant film market under its own name in 1975, Kodak saw no point in manufacturing negative for the second-generation cameras that would eventually be rendered obsolete by this new third-generation SX-70 line (Brand, 1972). As Kodak's president, Walter Fallon, upon viewing the SX-70, explained:

> "We are unwilling to divert further effort and funds from the development of our own Instant system into a secondary and more limited marketing opportunity." (Brand, 1972:6)

As this agreement was annulled, Kodak announced a crash program to come up with an Instant photography system of its own. As Liggero recalled:

> "In those days, Kodak was very concerned about Instant photography that it might displace Instamatic film, and our move into integral film almost surely hastened their own introduction of instant cameras." (Liggero, 2002)

Kodak's announcement led to the strengthening of Polaroid's resolve. It promised to develop a camera that was so advanced that "it would take Kodak years before it could catch up" (Liggero, 2002). Land proclaimed that Kodak didn't know what they were getting into, and that those who thought Kodak could catch up were "underestimating the power of [Polaroid's] imagination" (McElheny, 1998: 378). The technological complexity of Polaroid's film and its SX-70 camera were enhanced simply to keep Kodak at bay.

These dynamics capture processes of emergence involving interactions between physical (positive and negative) and social (Polaroid and Kodak) partitions (see Figures 1a and 1b). When Polaroid and Kodak first agreed to contract with one another across modular interfaces, Polaroid compromised its manufacturing processes for its positive to ensure compatibility with Kodak's installed processes for negative. These compromises were bound to generate tensions at the interfaces. Tensions started building up as Polaroid became financially strong to set up its own negative manufacturing facilities. Integration of the positive and negative implied endogenizing the transaction across social boundaries, a move that resulted in alienating Kodak. When Kodak threatened to enter the market with its own Instant system, the immediate outlook for Polaroid became bleak. Indeed, upon entry in 1976, Kodak captured a large chunk of the Instant market. In the meantime, Polaroid's stock plummeted because of Kodak's entry into a market that Polaroid had traditionally monopolized (Metz, 1978).

Integrating battery with film

Before the SX-70, Polaroid cameras had utilized standard batteries. However, the possibility of batteries running out in the middle of a roll was a primary source of user frustration.[4] Polaroid decided that the user must not have to worry about the instrument's power source. Polaroid decided that the battery must be in the film pack itself, which meant a fresh power supply would be introduced with every film (Olshaker 1978: 197). Thus, the user would be freed from the chore of changing batteries and the possibility of ever missing out on a 'Polaroid moment' because of dead batteries.

The new type of battery would "have to supply 6 volts of power at intervals of less than 2 seconds over a possible temperature range of nearly 100 degrees. And to fit into the film pack, it would have to be nearly flat" (Olshaker 1978: 197). These were unprecedented requirements for such a small battery. Even the 6 volts of power was acceptable only after Polaroid had spent considerable efforts to reduce the power consumed by the various camera components, a feat that was accomplished by utilizing advances in semi-conductor technology (Olshaker, 1978: 179). The camera segment containing the lens and shutter was modified after several false starts and costly mistakes. Eventually, three complex miniature circuits, controlling the motor, flash mechanism, shutter, and electric eye, coordinated each of the functions that took place in that

[4] Since, not only the shutter but also mirrors, film-advance system and flash sequencer were to be electronically controlled in the SX-70, a battery failure would have been devastating.

split second after the shutter button was pressed. As McElheny (1998:360) pointed out, the design emerged "interactively."

As was the case with the negative, technical challenges inherent in making a battery to required specifications were formidable. While the electrochemistry of the new batteries had been known for a century, the design and packaging formats were entirely new. About 19 layers of metal and plastic had to be bound and sealed to extremely small tolerances and incredible quantities (Cordtz, 1974). However, unlike the case of the negative, Polaroid intended to outsource the battery. First, Polaroid thought that battery requirements were precisely defined thereby making it possible for interfaces to be standardized. Outsourcing would divide labor, reducing the complexity of the entire camera for Polaroid and in freeing Polaroid to concentrate on other tasks. Second, there were no unanticipated consequences surrounding interactions between the battery and other camera components. It is no wonder that Polaroid never treated the battery as anything more than a peripheral component in earlier designs.

Thus, around 1968, with most details worked out on paper, Polaroid approached several battery suppliers to manufacture SX-70 batteries. After some search, in a textbook modular manner, Polaroid finally contracted the primary development of the battery out to ESB, Inc., a company that was highly regarded as the best in the field (McElheny, 1998:397). ESB, on its part, set up a special plant in Appleton, Wisconsin to manufacture SX-70 batteries. In other words, consistent with Baldwin and Clark's (2002) overall perspective on development of specifications that drive future interactions, Polaroid and ESB agreed to a set of specifications for carrying out distributed work.

Breaking apart from dealers and from ESB Upon being approached by Polaroid, ESB set up a special plant to manufacture SX-70 batteries. Just before the launch of the SX-70 in 1972, it came to light that ESB was struggling to stop chemical leakage from one chamber to another in the multi-chambered battery and to find the right combination of materials to assure charge retention for a period of longer than a few months (Cordtz, 1974). Thus, batteries had an unpredictable effective life, sometimes as short as two months. Limited introduction of the SX-70 towards the end of 1972 confirmed these fears. By the time a battery was manufactured, shipped to Polaroid, inserted in the film pack, and the film pack shipped to the retailer and eventually sold to a customer, there was often very little time during which it could be used before the battery would die. In the first several months of the SX-70's distribution, film pack returns because of dead batteries were extremely high (Olshaker, 1978).

The outcome not only altered the final design, but also, similar to the case of the negative, had severe consequences for Polaroid's socio-technical ensemble. Especially hit were Polaroid's dealers, key stakeholders in the ensemble. The short shelf life of batteries rendered several thousand film packs useless to retailers, adding to their mounting frustration (McElheny, 1998). As Dr. Sam Liggero recollected:

> "In the early 1970s, dealers were screaming for our products. So we shipped the SX in a rush. But when battery problems started appearing, they were mad at us. They were losing customers and they blamed us. The long-term consequences of this debacle were a more cautionary approach towards our products, which hurt us of course." (Liggero, 2002)

Polaroid reacted by opening service centers in major cities across the US in an effort to help consumers with their problems. The cost of getting the SX-70 products into operation and the problems with batteries and film returns and camera returns seriously affected Polaroid's earnings and resulted in substantial slowdown in the sales of both cameras and film, with Polaroid missing its 1973 sales goal by more than half (Olshaker, 1978: 204-5).

While the frustration of dealers, traditionally a critical part of Polaroid's socio-technical ensemble, was a major blow, it was not the only one. Prior to SX-70 Polaroid cameras had operated with ordinary standard batteries that were universally available and compatible with most electronics. Using these standardized batteries made it possible for Polaroid to take advantage of "external economies" (Langlois and Robertson, 1992) – the huge network of retailers who stocked standard batteries. Moreover, it allowed them to leverage consumers' familiarity and comfort with standard batteries. In addition, these batteries were multi-purpose. Thus, even if consumers had originally bought them for another purpose, these standard batteries could be used in Polaroid cameras. In sum, the decision to invent, modularize and outsource a non-standard battery ended up alienating Polaroid's dealer network as well as the vast and well-established network of dealers and retailers that was associated with standard batteries.

This was not the end of the story, though. In another unexpected development, it was discovered that pictures taken using the SX-70 film carried a blue-tinge, as if they had been taken "on a cold ski slope" (McElheny, 1998: 397). Upon investigation, Polaroid found that fumes from the battery were seriously degrading the color quality of the pictures (Liggero, 2002). Incorporating the battery into the film had resulted in coupling two components that had been "decomposed" at one point in time leading to unexpected interactions.

ESB, with all its specialized knowledge was unable to fix the problems that arose with the battery. For several months, Polaroid's engineers worked closely with ESB to fix the problem. Finally, unable to resolve the matter in this way, Polaroid began to set up its own brand new plant for manufacturing batteries. After months of trial and error, both with new materials and manufacturing techniques, in 1973, Polaroid started producing its own batteries (Figure 1b). The "Polabeam" battery remained active for up to 18 months. The gas leakage problem too, was addressed. This was accomplished once Polaroid engineers mastered the technique of sealing the batteries (McElheny, 1998: 398).

By the late 1970s, Polaroid was, by volume, one of the largest battery producers in the U.S. (Olshaker, 1978). Reflecting on the sequence of events that had led to this outcome, Polaroid's president Bill McCune declared shortly after the move was made: "We didn't intend to [get into the battery business]…We've been backed into it" (Olshaker, 1978).

Figures 1a and 1b depict the sequence of events defining interactive emergence of the physical and social architectures associated with the integration of the battery into the film. Initially, Polaroid and ESB started off with a textbook modular arrangement, interacting with one another through a transactional interface (Figure 1a). However, soon after problems developed in the new battery, Polaroid realized that the transactional interface did not allow joint problem solving. Knowledge film and battery were required and the formal contract between Polaroid and ESB made this difficult. Polaroid, thus, had no choice but to eliminate ESB from the ensemble, bringing battery manufacturing within a 'transaction-free' zone (Figure 1b).

Time pressures appear to have played a significant role in the processes defining interactive emergence involving the physical (film and battery) and social (Polaroid and ESB) partitions. Given unlimited time and resources, the problem could possibly have been resolved with the arrangement that existed between Polaroid and ESB. However, with the launch deadline looming nearer, Polaroid was constrained for time. As McElheny succinctly pointed out:

> "In a merciless triangle of time and money and specifications, it became painfully obvious that Polaroid…could not have all three. At least one of the three must yield." (McElheny, 1998:353)

Epilogue

The two technological decisions described above had serious consequences for Polaroid's organization and social network. In the first instance, the decision to make integral film on its own eliminated Kodak from Polaroid's ensemble, thereby not only depriving Polaroid of the benefits of modularity, but also turning Kodak into a direct competitor. This, in turn, changed Wall Street's outlook on Polaroid, leading to a fall in its stock price and rating. In the instance of the battery, Polaroid opted for the benefits associated with modularity. However, opting for a non-standard battery and pursuing a modular arrangement with ESB resulted in the alienation of Polaroid's dealer network as well as the network associated with standard batteries, with Polaroid eventually forced into manufacturing batteries.

The integration of the positive and negative and the inclusion of the battery into the film were just two of the many changes that took place in the creation of the SX-70 camera. During the design process, "every component pushed the other" (Buckler quoted in McElheny, 1998: 354), leading to a corresponding set of interactions between Polaroid and its stakeholders. In a separate instance, not narrated here, Polaroid's efforts to miniaturize the camera led to a complex set of interactions with Texas Instruments and with Fairchild Camera, with the latter eventually dropping out of the relationship (McElheny, 1998).

These incidents underscore the larger interdependencies between components of the ensemble, on the one hand, and those who had agreed to design and manufacture them on the other. It was not just the operation of the camera—its shutter, film development for instance—that had to be 'designed.' Equally importantly, Polaroid had to stitch together the commitments and actions of a whole group of social entities. When even one of the links in this complex web of interdependencies was broken, Polaroid's carefully laid out plans would unravel, thereby initiating a fresh round of evaluations.

This domino effect was evident, for instance, in several suppliers' decision to halt production of parts for the SX-70. Corning was one such supplier, which attributed its decision to stop the production of SX-70 lens to insufficient volume from Polaroid to keep operations profitable (Wall Street Journal, 1975). Similarly, other vendors cancelled their contracts with Polaroid, plunging it deeper into trouble.

To sum up, Polaroid's decision to radically alter its existing design had repercussions far beyond the technical realm. At every stage of the design's emergence, new social dynamics materialized causing fundamental changes in the specifications and partitioning of the whole design. Many of the partitioning decisions were motivated by concerns other than "mundane transaction costs" (Williamson, 1985; Baldwin & Clark, 2002). Finally, in the course of this odyssey, Polaroid's organization and its relationships with stakeholders were completely altered.

DISCUSSION

We began the paper by offering a perspective that views designs as socio-technical ensembles. When applied to the SX-70 case, this perspective yielded several insights. First, rather than a static combination of physical components, socio-technical ensembles are dynamic agglomerations of interests. Underlying apparently stable architectures are tensions that act as antecedents to radical innovation. Second, radical innovation involves transformations, bringing in its wake a re-alignment of existing technical and social architectures. Indeed, distinctions such as core and periphery are not a given, but instead emerge during the course of change. Third, in contrast to evolutionary (Simon, 1962) or engineered (Petroski, 1996; Baldwin and Clark, 2002) notions, radical innovation unfolds in an interactive fashion wherein physical and social partitions are both cause and consequence of underlying dynamics. At every stage, competitive dynamics, tensions at the interfaces, strategic actions, anticipated and unanticipated consequences, time pressures and individual judgments shape the processes underlying radical innovation. Fourth, any change to the physical architecture disrupts the social architecture underlying designs. Consequently, social re-arrangements that take place with component recombinations may end up destroying the social support required for commercial success to ensue. We discuss these propositions in greater detail.

Designs as dynamic ensembles

The allure of modularity lies in its potential to create a system that operates seamlessly across standardized interfaces. Scholars ranging from Hayek (1945) to Hughes (1983) have offered compelling perspectives on the functioning of distributed systems. In these conceptualizations, once the functioning of a design has stabilized, various constituents do not need to know what the other is doing. The socio-technical ensemble can operate seamlessly as a series of black boxes stitched together by interface specifications and inter-firm contracts.

The SX-70 case illustrates that the social interfaces across which transactions occur may not be as stable as this rather neat image of modular systems suggests. Rather, interfaces are ripe with tensions that arise from the constraining role of contracts governing transactions. Thus, while Polaroid's relationship with Kodak was convenient in many ways, it nevertheless constrained Polaroid from introducing any significant changes in its design because of Kodak's reluctance to change the specifications of the negative.

Another related source of tension is partners' reluctance to share more information than stipulated under the contract. This was exemplified by Kodak's refusal to share any knowledge of negative manufacturing with Polaroid. Polaroid's insistence on knowing more about negatives is revealing. By doing so, Polaroid appeared to be neutralizing what is taken to be modularity's biggest benefit: division of physical and cognitive labor, or the ability to black box sets of activities (Simon, 1962; Sanchez and Mahoney, 1996; Schilling, 2000). Brusoni, Prencipe and Pavitt (2001) have challenged this perspective to suggest that systems integrators need to know more than they make in order to cope with imbalances caused by uneven rates of development in the technologies upon which they rely. The SX-70 case suggests additional reasons.

Specifically, strategic considerations appeared to have over-ridden economic benefits from modularity. Typically, interdependent parties learn from each other (Hamel, Doz and Prahalad, 1989), but in the case of Polaroid and Kodak, mutual secrecy appears to have led each firm to generate its own set of competencies. Tensions flared up between the two companies as and when one firm came to know of the other's competencies.

The Polaroid-Kodak vignette points to the fragility that is inherent in seemingly stable structures. In order to understand the dynamics of radical innovation and how particular architectures are adopted, it is important to realize the existence of these dynamic tensions within designs. Contracts enable the functioning of a system in real time but they can constrain its emergence over time (Klein, 1988). Any member of such a socio-technical ensemble may attempt to break this duality of contracts by trying to overcome its constraining effects. Such attempts trigger a sequence of events that have a profound influence on the emergence of the new architecture.

These dynamics may be obscured if we focus on physical interfaces alone. By viewing designs as bundles of interests, we not only avoid this possibility, but also become more sensitive to the changes that are brewing beneath the surface and setting the stage for radical innovation. From this perspective, any re-arrangement, addition or elimination of components ceases to be a mere technological endeavor. These changes re-constitute the economic interests of associated actors and the social dynamics that are set in motion play a critical role in determining the partitions that emerge.

Transformative change

The SX-70 case offers useful insights into the dynamics associated with radical innovation. First, as this case suggests, the location of partitions to achieve black boxing is not pre-given, but, is emergent. Thus, Polaroid's efforts at reducing complexity for one constituent—customers, in this case—resulted in increasing complexity for other constituents, e.g., producers and distributors. In order to provide its customers with a one-step experience, the inside of the rest of the socio-technical ensemble was transformed. The transformation itself was marked by dramatic changes in the shape and configuration of parts, many of which were integrated. With each component 'pushing the others' Polaroid had to make several unplanned changes in both components and the architecture. In this manner, the location of partitions to achieve black boxing was not pre-given but constructed.

Analyzing the integration of various parts yields a second related insight: core and periphery cannot be entirely pre-specified on the basis of number of linkages to other parts or the 'centrality' of a particular component. Instead, the actual significance of a part emerges in an interactive fashion. To appreciate this point, we return to the distinction between core and periphery that we had introduced earlier. These distinctions can be traced to an understanding of designs as hierarchies with some components being more trenchant than the others (Clark, 1985). Accounts of change, within such a conceptualization, focus on the functionality of the components and the interdependency between them. Thus, the more 'critical' a component is to the 'overall identity' of the technology the more 'core' it is (Griffith, 1999). Similarly, in terms of relationships, the more 'tightly connected' a 'subsystem' is to the rest, the more 'core' it is perceived to be (Tushman and Murmann, 1998).

Existing conceptualizations of core and periphery were of little help in determining which components were 'core' in the film. Was it the negative, the opacifying dyes or the positive? In order to produce SX-70 films, Polaroid had to work on all three along with several other components of the film. The interactions were great and interdependencies many. Similarly, in the entire camera-film system, was the camera core or the film? Going by functionality (Griffith, 1999) it is difficult to say. Similarly, the criterion of 'tight coupling' (Tushman and Murmann, 1998) would point to the battery as a peripheral subsystem. However, due to a design specification in the architecture, a component level change in the battery was required. The change in location for the battery (Figure 4a and 4b) led to unexpected interactions between the battery and other components. With these interactions, the status of the battery was raised to a core component at least until the design had stabilized.

-- Insert Figures 4a and 4b here --

Viewing designs as socio-technical ensembles provides a more nuanced perspective on the relationships between different components. As soon as we realize that the components of the SX-70 represented not only technological knowledge but also interests, we can discern that relationships among components are more complex than they appear on the surface. Vested interests, social tensions, as well as the nature of transactional interfaces influence the actual significance of a component and the extent to which it can be transformed.

Thus, in order to appreciate the real significance of the negative, one needs to take into account Kodak's economic power. All dynamics surrounding the negative were influenced by the asymmetry in position between Polaroid and Kodak. For instance, to overcome this asymmetry, Polaroid decided to 'know more' than what it needed (Brusoni, Prencipe & Pavitt, 2001). At the same time, it shaped Polaroid's options with respect to possible changes. Similarly, the type of relationship that Polaroid chose to have with ESB enormously influenced the significance of the battery and had serious, long-term implications for Polaroid's future competitiveness.

In order to understand the dynamics of radical innovation and the emergence of an eventual architecture, we have to know not only the functional significance of various components, but also the social. Alterations to architectures occur through a political process that is managed by organizational actors who are motivated by social and economic considerations. In such a political process, viewing components in terms of their 'core' or 'peripheral' status based upon their position in the technical hierarchy can serve to mislead managers, as turned out to be the case with Polaroid.

Interactive emergence

Literature often depicts the evolution of design as a process that unfolds either in an evolutionary fashion (Simon, 1962) or in a pre-designed fashion (Petroski, 1996; Baldwin and Clark, 2002). Our analysis suggests that partitions within designs are neither an outcome of a process devoid of human involvement nor are they results of pre-designed processes. Instead, partitions emerge in response to social dynamics which themselves are functions of existing partitions.

There was no inevitability about the way the SX-70 emerged. At any given point in time, the emergence of the socio-technical ensemble underlying the SX-70 (i.e., the architecture, components, stakeholders and location of transactions between modules) was determined at every stage by several factors. These included organizational dynamics, constantly changing strategic imperatives, arising contingencies in the shape of unfolding technological developments or an inability of contractors to deliver, as well as by trade-offs between time, specifications and resources.

Such interactive emergence played out at different levels. SX-70 specifications enhanced unpredictable interdependencies between the various layers of the film. For instance, Polaroid's past experience with Kodak and the tensions at the interface of the two companies led to an outcome where Polaroid decided to develop and produced the negative in-house. Indeed, this decision made it possible for Polaroid's engineers to explore solutions to challenging problems as they emerged. Moreover, once Kodak had declared 'war' on Polaroid, it became Polaroid's priority to take a long, insurmountable lead over Kodak. The explicit goal of introducing more complexity through greater integration of various engineering processes profoundly influenced the ultimate design of the SX-70.

The design of the battery necessitated reducing power requirements in the design. This was made possible by re-designing major parts of the camera using state-of-the-art miniaturization technology that Polaroid did not possess at that time. Naturally, the process of redesigning several highly interdependent parts was iterative in which several solutions were tried for every problem that arose. Similarly, when fumes from the battery began interacting with the chemicals in the film, intensive transfers of knowledge across the transactional interface between ESB and Polaroid became necessary, eventually resulting in a clean break between the two and necessitating a completely revised design of the battery, now manufactured wholly within Polaroid.

Thus, the emergence of the SX-70 was not a process that proceeded linearly from architecture to interfaces. Rather, it was an iterative process wherein the technological architecture co-emerged with the social architecture underpinning it. Indeed, in real time, it was never entirely predictable where the final partitions would be or what the new black boxes would look like.

These observations have implications on component complementarities. Recently, Novak and Stern (2003) have argued that component complementarities determine decisions as to whether or not to outsource a specific component. By demonstrating empirically the validity of this proposition, Novak and Stern (2003) go beyond a conceptualization that considers transactions on a component-by-component basis, thereby advancing our understanding of the division of physical and cognitive labor. The SX-70 case adds valuable extensions to Novak and Stern's contributions. Specifically, it points to the endogeneity of complementarities between components, an integral part of interactive emergence. For instance, the negative and positive were modular at one point in time, but became integral at another. Similarly, the battery and the film, which were modular components at one time became integrated at another, despite efforts to keep them modular.

Time pressures played an important role in the emergence of the SX-70 design as well. To bring about radical innovation, firms have to orchestrate the production of various components by different actors at different points in time. As a result, time and timing becomes a critical factor especially given the uncertainties inherent in radical innovation. In this regard, McElheny (1998:353) suggested that trade-offs between "time, resources and specifications" shaped the SX-70 breakthrough right from the beginning. If members of the SX-70 socio-technical ensemble had available to them all the time and the resources required to see the changes through, perhaps a strictly modular design enabling distributed and parallel processing across transactional interfaces may have materialized; perhaps ESB or Polaroid could have fixed the problem. However, given the time pressures imposed by an impending deadline, these contingencies became turning points in the trajectory of the design, in turn leading to new dynamics. For instance, Polaroid eventually ended up designing and manufacturing the battery to ensure that the rest of the SX-70 effort would not be held-up for the lack of an appropriate battery.

Indeed, trade-offs between time, specifications and interests determine what the new modules will be, where the system boundaries will lie, and who will eventually get to manufacture specific modules. Time is not an exogenous element that determines what prevails. Time itself is a strategic variable that architects of breakthroughs have to manage. Eventually, the new technical and social architectures that emerge bear the imprints of the interests and specifications that get etched out in the design over time.

Breaking through and breaking apart

So far, we have suggested that socio-technical ensembles are dynamic congregation of parts, radical innovation entails a transformation of existing architectures and that the nature of transformation is best described as a process of interactive emergence. Building upon these propositions, our final proposition gets to a critical challenge of orchestrating radical innovation -- where technical partitions are eliminated, social ones may be created. This proposition is depicted in Figures 1a and 1b. For instance, Polaroid decided to eliminate the transactional interface with Kodak and bring the negative in-house. In the process, Kodak was cast out of the socio-technical ensemble.

The SX-70 case illustrates how and why such outcomes are likely to emerge with radical innovation. Radical innovation often requires a recombination of knowledge across partitions (Fleming & Sorensen, 2001; Hargadon, 2003; Iansiti, 1998; Okhuysen and Eisenhardt, 2002; Rosenkopf & Nerkar, 2001; Usher, 1954). In order to bring about such recombination, existing social arrangements may need to be dramatically altered. In the process, the interests of the firms whose interests are embedded in the various modules of an existing design may be compromised. Thus, processes and arrangements required for successful technological re-combination are the very ones that end up destroying the social support required to sustain the radical innovation once it has materialized.

For instance, difficulties in making the SX-70 integral film without combining the previously separated repositories of knowledge (negative and positive) resulted in the termination of the relationship between Polaroid and Kodak. Similarly, difficulties in incorporating the battery into the film resulted in the termination of the relationship between Polaroid and ESB. Not surprisingly, members of Polaroid's socio-technical ensemble did not greet Polaroid's extrication of physical modules from their social moorings with great enthusiasm. In the case of the battery, the seemingly benign outcome was that Polaroid was backed into manufacturing batteries when ESB could not solve the "fumes" problem. The radically new battery estranged Polaroid's emergent SX-70 ensemble from the well-established standard batteries network. It also ended up alienating film dealers because they were compelled to adopt a new stocking schedule to match the battery shelf life. In the case of film layers, the peeling apart of the negative from Kodak's clutches provoked a counter response. Kodak, once Polaroid's collaborators, went on to become Polaroid's most formidable competitor. Kodak's entry, as a competitor, significantly diminished Wall Street's faith in Polaroid.

Teece (1987) identified reasons for why technological breakthroughs could become Phyrric victories for first movers. In many instances, innovators pursue an inappropriate course of action based on their misunderstanding of the tightness of their intellectual property protection or based on their underestimation of the importance of co-specialized assets required to commercialize an innovation (see also Tripsas, 1997). Lacking either adequate intellectual property protection or co-specialized assets, innovators, who decide to go it alone, are likely to be overtaken by others.

Polaroid's SX-70 case adds additional light on these observations. Polaroid possessed a thicket of patents that it hoped would delay if not prevent Kodak from catching up. Moreover, it used its own resources to create the co-specialized assets whenever it found that outside suppliers were either unable or unwilling to create them. Yet, success eluded Polaroid because it was unable to mobilize the support of key members to the emerging socio-technical ensemble quickly enough to gain cognitive and political legitimacy (cf. Aldrich and Fiol, 1994; Munir, 2003; Van de Ven 1993). In the very process of orchestrating radical innovation, Polaroid ended up either alienating or distancing itself from its earlier support network. In other words, Polaroid failed to embrace a 'robust design' strategy, one that may have offered them with an opportunity "to exploit the established institutions while simultaneously retaining the flexibility to displace them" (Hargadon & Douglas, 2001:476).

CONCLUSION

We began the paper by highlighting the significant impact that radical innovation can have in shaping the fortune of firms in the modern economy. We suggested that gaining a deeper appreciation of the micro-processes involved could add significantly to our understanding of how firms might be able to orchestrate radical innovation to their advantage. In this regard, it is important to view technological systems as comprising more than just physical modules that operate across standardized interfaces. Physical partitions have corresponding social analogues, and such an understanding brings into play the interests of the many actors involved.

In line with this broader understanding, it is fruitful to view these designs as socio-technical ensembles. Various system components derive their importance not just from their contributions to the overall functionality of the design, but also from the specific interests of the stakeholders that they serve. Interfaces, from such a perspective, represent compromises reached in the process of aligning interests. These agreements not only enable but also constrain, leading to tensions at the interfaces that set the stage for radical innovation to occur. In other words, a socio-technical ensemble perspective makes it possible to endogenize antecedents to radical innovation.

Moreover, a socio-technical ensemble perspective offers a more nuanced understanding of the processes whereby radical innovations unfold. As our study of the SX-70 camera uncovered, rather than being a case of 'survival of the fittest', radical innovation is shaped by agency at all points of the innovation journey. Moreover, rather than being driven solely by engineering and transaction cost considerations, radical innovation, such as the SX-70 camera, is equally influenced by strategic and organizational ones.

As a result, firms that try to orchestrate radical innovation often confront a paradox. On the one hand, radical innovation involves recombination of once separate modules. Yet in accomplishing such recombination, a firm may destroy the very support of its existing social network, support that is essential to sustain the radical innovation.

Can firms be too innovative for their own good? The findings from our study offer a necessary note of caution. The process of interactive emergence that we have detailed suggests that firms must consider both the technical and social architectures in their deliberations when they attempt radical innovation. Indeed, it is the conflicting relationship between innovation and enrolment of stakeholders that a firm must recognize if it is to successfully negotiate radical innovation.

REFERENCES

Alexander, C. (1964) Notes on the Synthesis of Form. Cambridge, MA: Harvard University Press.

Aldrich, H.E. & Fiol, C.M. (1994) Fools rush in? The institutional context of industry creation. *Academy of Management Review*, 19: 645-670.

Anderson, P. & Tushman, M.L., (1990) Technological discontinuities and dominant designs. *Administrative Science Quarterly*, 35: 604-633.

Baldwin, C.Y. & Clark, K.B. (2000) Design Rules, Volume 1, The Power of Modularity. Cambridge, MA: MIT Press.

Baldwin, C.Y. & Clark, K.B. (2002) Where do transactions come from? A perspective from engineering design. *Harvard Business School Working Paper*.

Bijker, W. E. (1995) The social construction of Bakelite: Toward a theory of invention, in W. Bijker, T. Hughes, & T. Pinch (Eds.), The Social Construction of Technological Systems. Cambridge, MA: MIT Press.

Bijker, W. & J. Law (Eds.). (1992) Shaping Technology, Building Society: Studies in Sociotechnical Change. Cambridge, MA: MIT Press.

Brand, D. (1972) Kodak won't make Polaroid Instant film, plans to sell rival film, camera instead. *Wall Street Journal*, 20 Nov 1972, p.6.

Brusoni, S., Prencipe, A. & Pavitt, K. (2001) Knowledge specialization, organizational coupling and the boundaries of the firm: Why do firms know more than they make? *Administrative Science Quarterly*, 46: 597-621.

Callon, M. (1986), The Sociology of an Actor-Network: The case of the electric vehicle. In Callon, M., Law, J., & Rip, A. (Eds.), *Mapping the Dynamics of Science and Technology*, Macmillan, London.

Campbell DT. (1975) "Degrees of freedom" and the case study. *Comparative Political Studies* 8: 178-193.

Christensen, C. (1997) The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail. Boston, MA: Harvard Business School Press.

Clark, K. B. (1985) The interaction of design hierarchies and market concepts in technological evolution. *Research Policy*, 14: 235-251.

Cordtz, D. (1974) How Polaroid bet its future on SX-70. *Fortune*, Jan 1974, 89: 82-147.

Ethiraj, S. and Levinthal, D. (2002) Modularity and innovation in complex systems, *Academy of Management Best Papers Proceedings*, pp. C1–C6.

Fleming, L. & Sorenson, O. (2001) Technology as a complex adaptive system: Evidence from patent data. *Research Policy*, 30: 1019-1039.

Galunic, C. and Eisenhardt, K. (2001) Architectural innovation and modular corporate forms. *Academy of Management Journal*, 44/6:1229-1249.

Garud, R. and Rappa, M. (1994) A socio-cognitive model of technology evolution *Organization Science* , Vol. 5, No. 3, pp. 344-362.

Garud, R. & Karnøe, P. (2003) Bricolage vs. breakthrough: Distributed and embedded agency in technology entrepreneurship. *Research Policy*, 32, 277-300.

Garud, R. & Kumaraswamy, A. (1995) Technological and organizational designs to achieve economies of substitution. *Strategic Management Journal*, 16: 93-110.

Gilfillan, S. C. (1935) The Sociology of Invention, Chicago: Follett Publishing Company.

Glaser B, & Strauss A. (1967) The Discovery of Grounded Theory: Strategies of Qualitative Research. London, UK: Wiedenfeld and Nicholson.

Griffith, TL (1999). Technology features as triggers for sensemaking. *Academy of Management Review*, 24, 472-488.

Hamel, G., Doz Y. & Prahalad. C. K. (1989) Collaborate with your competitors -- and win. Boston, MA: Harvard Business Review. 67. 1. pp. 133-139.

Hargadon, A. (2003) How Breakthroughs Happen: The Surprising Truth About How Companies Innovate, Cambridge, MA: Harvard Business School Press.

Hargadon, A. & Douglas, Y. (2001) When innovations meet institutions: Edison and the design of the electric light. *Administrative Science Quarterly*, 46: 476-501.

Hayek, F.A. (1945) The use of knowledge in society. *The American Economic Review*, 35: 519-532.

Henderson, R. & Clark, K. (1990) Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms. *Administrative Science Quarterly*, 35: 9-31.

Hughes, T. (1983) Networks of Power: Electrification in Western Society, 1880-1930. Baltimore, MD: Johns Hopkins University Press.

Iansiti, M. (1998) Technology Integration: Making Critical Choices in a Dynamic World. Boson, MA: Harvard Business School Press.

Kemp, R. Schot, J. & Hoogma, R. (1998) Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. *Technology Analysis & Strategic Management*, 10: 175-195.

Kidder, T. (1981) The Soul of a New Machine. London, UK: Allan Lane.

Klein, B. (1988) Vertical integration as organizational ownership: The Fisher Body-General Motors relationship revisited. *Journal of Law, Economics, and Organization*, Vol. 4, No. 1, pp. 199-213.

Langlois, R. (2003) The vanishing hand: The changing dynamics of industrial capitalism, *Industrial and Corporate Change* 12(2): 351-385 (April 2003)

Langlois, R.N. & Robertson, P.L. (1992) Networks and innovation in a modular system: Lessons from the microcomputer and stereo component industries. *Research Policy*, 21: 297-313.

Latour, B. (1991) Technology is society made durable, In: A Sociology of Monsters. Essays on Power, Technology and Domination., (Ed, Law, J.), Routledge, London, pp. 103-131.

Leifer, R., McDermott, C., O'Connor, G., Peters, L., Rice, M. and Veryzer, R. (2000) Radical Innovation: How Mature Companies Can Outsmart Upstarts, Cambridge, MA: Harvard Business School Press.

Life Magazine (1972). A genius and his magic camera. October 27: 42-48.Liggero, A. (2002) Transcript of interview (Available upon request).

MacKenzie, D. & Wajcman, J. (Eds.). (1985) The Social Shaping of Technology. Milton Keynes: Open University Press.

March, J. G., Sproull, L. S., & Tamuz, M. (1991) Learning from samples of one or fewer. *Organization Science*, 2: 1-13.

McElheny, V. (1976) "Business Trends: A technological explosion in photography," New York Times, Jun 4, pp77

McElheny, V. K. (1998) Insisting on the Impossible: The Life of Edwin Land. Reading, MA: Perseus Books.

McElheny, V. K. (2002) Transcript of interview (available upon request).

Merry, Glenn. (1984) Polaroid—Kodak. Harvard Business School Case: 376-266.

Metz, R. (1978) Analysts' view of Polaroid, New York Times, July 26, D6.

Miles, M. & Huberman, M. A. (1984) Qualitative data analysis: A source book of new methods, Beverley Hills, CA.: Sage Publications.

Mohr, L. B. (1982) Explaining Organizational Behavior: The Limits and Possibilities of Theory and Research. San Francisco, CA: Jossey-Bass.

Munir, K. (2003) Competitive dynamics in face of technological discontinuity: A framework for action. *Journal of High Technology Management Research*, 14: 93-109.

Novak, S. & Stern, S. (2003) Complementarity among vertical integration decisions: Evidence from automobile product development. *Paper presented at 2003 Wharton Technology Miniconference*.

Okhuysen, G. A. & Eisenhardt, K. M. (2002) Integrating knowledge in groups: How formal interventions enable flexibility. *Organization Science*, 13: 370-386.

Olshaker, M. (1978) Instant image: Edwin Land and the Polaroid experience. New York: Stein and Day.

Petroski, H. (1996) Invention by Design: How Engineers Get from Thought to Thing. Cambridge, MA: Harvard University Press.

Polaroid Annual Reports (1972 & 1974) Polaroid Corporation.

Reinhold, R (1972) Land achieves his dream with new Polaroid SX-70, *The New York Times*, October 30, pp. 47.

Rosenkopf, L. and Nerkar, A. (2001) Beyond local search: Boundary spanning, exploration, and impact in the optical disc industry. *Strategic Management Journal*, 22: 287-306.

Sanchez, R. & Mahoney, J.T. (1996) Modularity, flexibility and knowledge management in product and organizational design. *Strategic Management Journal*, 17: 63-76.

Schilling, M.A. (2000) Towards a general modular systems theory and its application to interfirm product modularity. *Academy of Management Review*, 25: 312-334.

Schumpeter, J.A. (1950) Capitalism, socialism and democracy. Reading, MA: Addison-Wesley.

Siekman, P. (1970) Kodak and Polaroid, An End to Peaceful Coexistence. Fortune, November 1970: 82-83.

Simon, H.A. (1962) The architecture of complexity. Proceedings of the American Philosophical Society, 106: 467-482. Reprinted in *idem, The sciences of the artificial*, 4th edition: 183-216, 1998, Cambridge, MA: MIT Press

Steadman, P. (1979) The evolution of designs: Biological analogy in architecture and the applied arts. Cambridge: Cambridge University Press.

Teece, D.J. (1987) Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. In D.J. Teece (Ed.), *The Competitive Challenge: Strategies for Industrial Innovation and Renewal* (pp. 185-219). Cambridge, MA: Ballinger.

Thomas, R. J. (1994) What Machines Can't Do: Politics and Technology in the Industrial Enterprise. Berkeley: University of California Press.

Time Magazine (1972) Polaroid's big gamble on small cameras. June 26: 80-87.

Tripsas, M. (1997) Unraveling the process of creative destruction: Complementary assets and incumbent survival in the typesetter industry. *Strategic Management Journal* Vol. 18 Issue 6, p119-143.

Tripsas, M., & Gavetti, G. (2000) Capabilities, cognition, and inertia: Evidence from digital imaging. *Strategic Management Journal*. 21: 1147–1161.

Tushman, M. & Murmann, J.P. (1998) Dominant designs, technology cycles, and organizational outcomes. *Research in Organizational Behavior*, 20: 231-266.

Ulrich, K.T. & Eppinger, S.D. (2000) Product Design and Development. New York: Irwin McGraw Hill.

Usher, A. (1954) A History of Mechanical Inventions. Cambridge, MA: Harvard University Press.

Utterback, J. (1994) Mastering the Dynamics of Innovation: How Companies Can Seize Opportunities in the face of Technological Change, Boston, MA: Harvard Business School Press

Van de Ven, A. H. (1992) Suggestions for studying strategy process: A research note. *Strategic Management Journal*, 13, 169-188

Van de Ven, A. H. (1993) A community perspective on the emergence of innovations. *Journal of Engineering and Technology Management*, 10: 23-51.

Wall Street Journal (1975) Corning Glass to halt output of camera lens for Polaroid's SX-70s, 22 July, p.11.

Wensberg, P. C. (1987) Land's Polaroid: A Company and the Man who Invented it. Houghton Mifflin.

Williamson, O. (1985) The Economic Institutions of Capitalism. New York: Free Press.

Ziman, J. (2000) Evolutionary models for technological change, In J. Ziman (ed.) Technological Innovation as an Evolutionary Process, Cambridge: Cambridge University Press.

TABLE 1: CHRONOLOGY OF EVENTS IN THE EMERGENCE OF SX-70

Year	Event
1937	• Polaroid Corporation formed.
1948	• Instant photography introduced.
1950	• One million rolls of instant film manufactured. First black and white instant roll film, Type 41, introduced.
1957	• Polaroid listed on the New York Stock Exchange.
1963	• Instant color film introduced.
1964	• 4-for-1 stock split. • Preliminary work on SX-70 begins.
1967	• Search for opacifying dyes (chemical 'curtain') begins.
1968	• Opacifier concept demonstrated for the first time. • Polaroid begins negotiations with ESB for battery manufacture.
1969	• Polaroid's net sales reach $536 million, with net earnings at $71 million. • Kodak and Polaroid change agreement. Kodak agrees to continue manufacturing negatives for Polaroid in return for a license to enter the peel-apart instant film market in 1975. • A working prototype of the opacifying dyes is demonstrated. • Polaroid begins negotiations with Corning to build lenses, and General Electric to build a special flash unit.
1971	• Kodak announces that it would come out with its own Instant camera and film system to rival Polaroid's by 1975.
1972	• Negative manufacturing plant completed. • Work on anti-reflection coating begins in August. • In anticipation of SX-70, Polaroid's stock climbs to almost $120. • In late summer, a blue tinge was observed in photos taken on SX-70 Integral film. • Limited introduction of SX-70 camera in Southern Florida. • After viewing the SX-70, Kodak announces that it is no longer interested in making film for Polaroid's Peel-apart cameras. Kodak abandons its plans to manufacture its own Peel-apart Instant camera and film system and decides to focus on producing a system based on Integral film instead. • After ESB was unable to fix battery problems, Polaroid makes changes to the battery design and starts building its own battery manufacturing plant.
1973	• The SX-70 is introduced nation-wide, nine months late. • Problems with batteries (short shelf-life and leakage) persist, to the annoyance and frustration of dealers. • Polaroid produces first batch of batteries. • Polaroid fails to meet its 1973 sales goal by more than half (sold 415,000 instead of the projected 1 million).
1974	• Business Week reports in November that of the 2 million SX-70 cameras sold to dealers by fall, half still rest on dealer's shelves. • Polaroid stock falls to $14 from a peak of $149. • Sales rise 10% but profits sink 45%. • Polaroid introduces cheaper versions of the SX-70, shifting its focus to mass-market cheap cameras. As a result, there is an increased gap between the quality of Instant cameras and that of Kodak's new, expensive, 35mm, SLR, cameras.
1975	• Corning cancels contract with Polaroid to make lenses for the SX-70. Two other vendors follow suit.
1976	• Kodak introduces its own Instant camera with Integral film and quickly captures about one-third of the market.

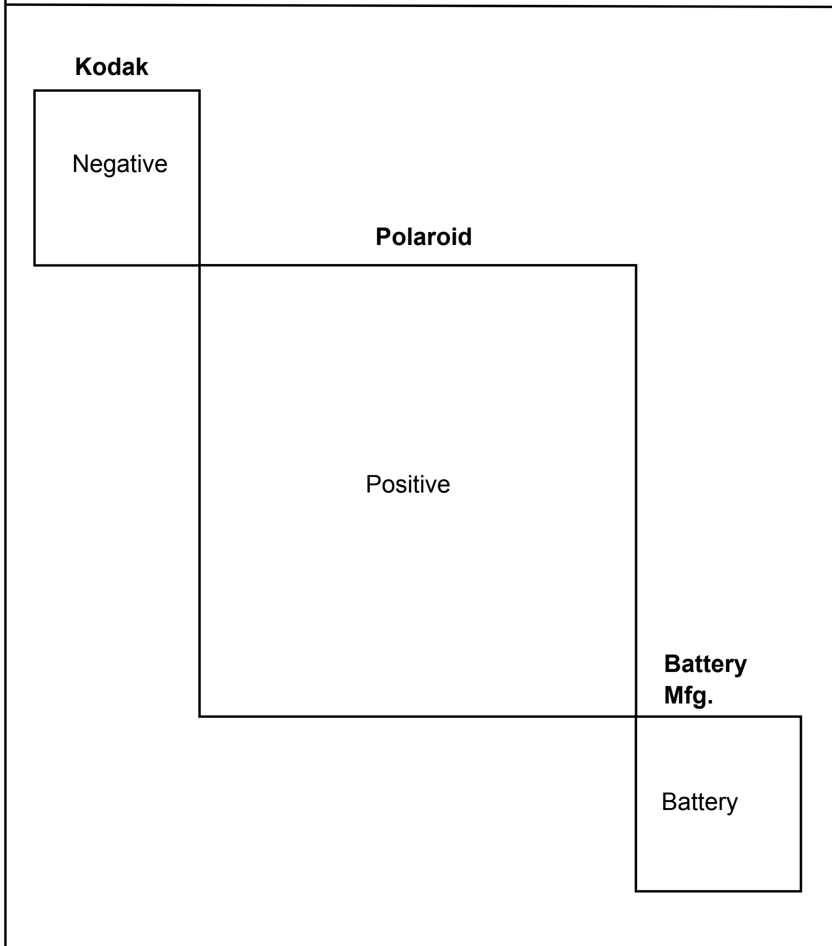


Figure 1a: Socio-Technical Ensemble < SX70

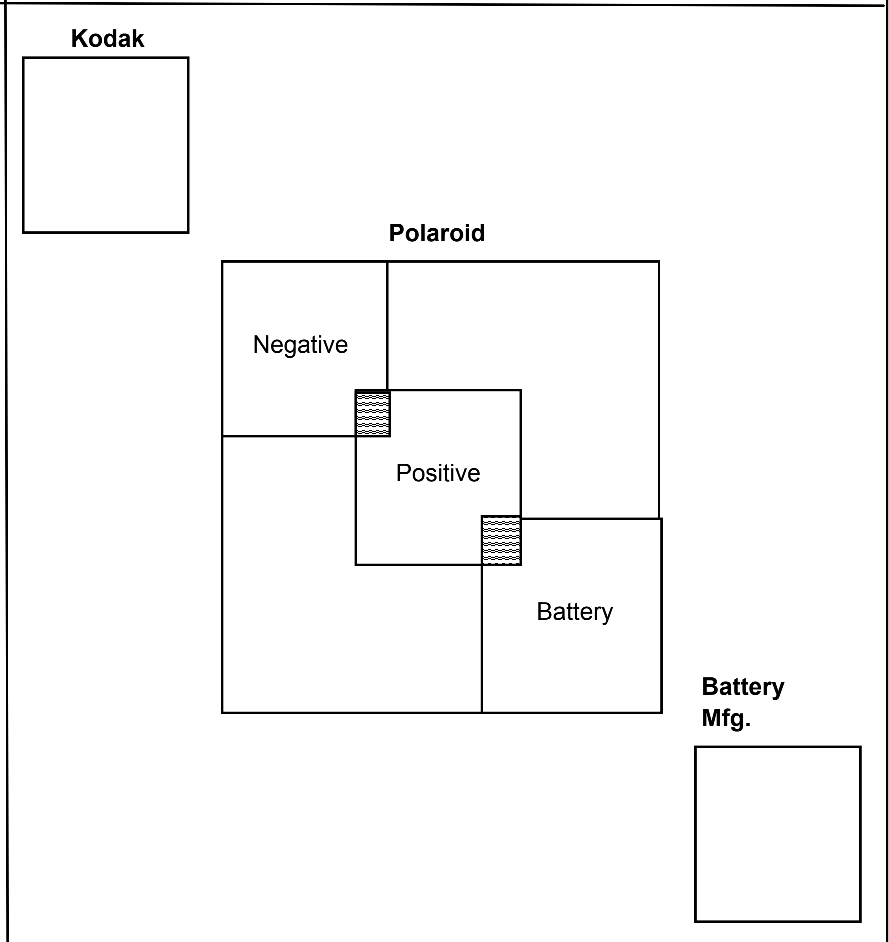


Figure 1b: Socio-Technical Ensemble > SX70

Figure 2: Schematic of the SX-70 Camera

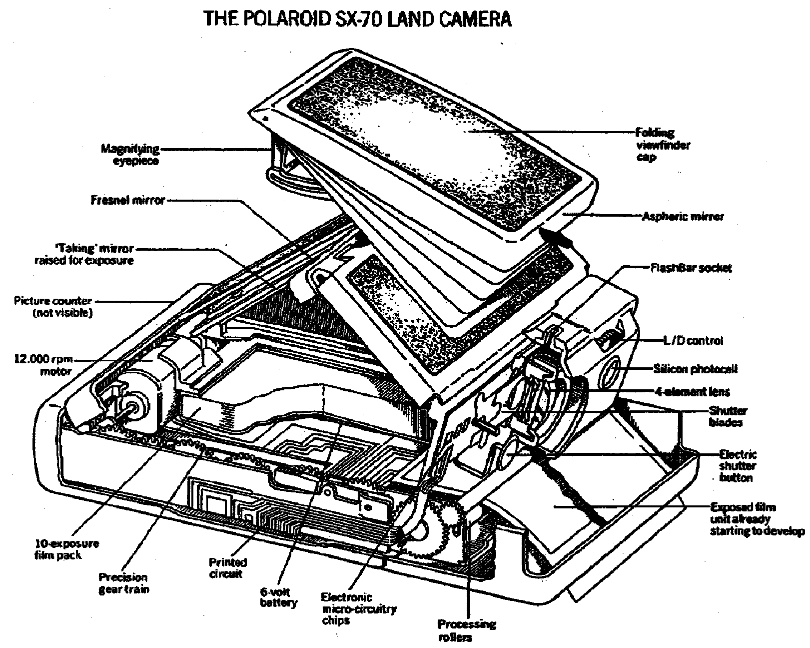
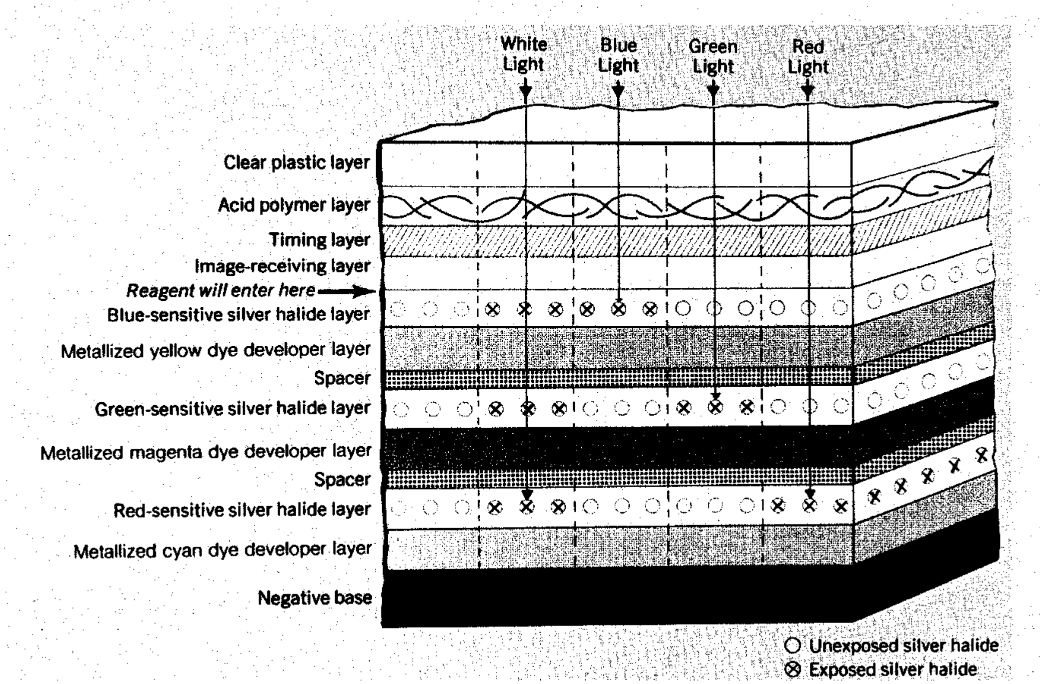


Figure 3: Schematic of the Film Layers



In the earlier Polaroid film, there were at least eight layers in the negative. Three of the layers contained silver halide crystals sensitized to one part of the visible spectrum: blue, green, and red. Adjacent to each was a layer of dye whose color was complementary to the color to which the layer above was sensitized -- that is, yellow, magenta, and cyan. The major innovation was the linking of the dyes to developer groups. Spacers, designed to govern the rate at which dyes were released from the negative to migrate to the positive, separated these pairs of layers from each other. When a photon of light struck a silver halide grain, dye-developers rising from just beneath would bind to the halide grain above. But all other dye developers would keep on going, through the processing fluid to a very thin layer in the positive where the dyes subtracted from the negative would build up into the positive color picture.

Figure 4a: System Hierarchy < SX70

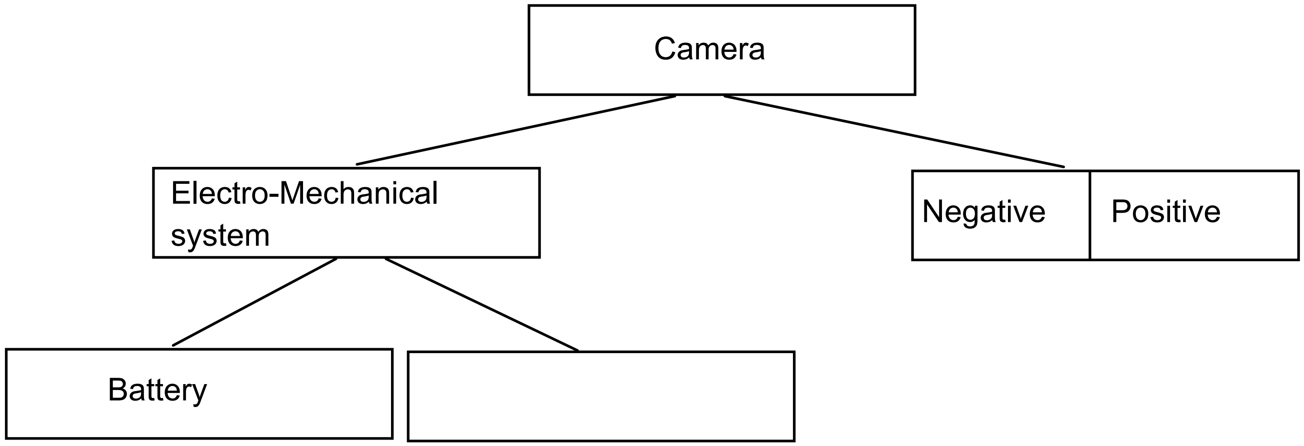


Figure 4b: System Hierarchy > SX70