Technology Brokering and Innovation in a Product Development Firm

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We blend network and organizational memory perspectives in a model of technology brokering that explains how an organization develops innovative products. The model is grounded in observations, interviews, informal conversations, and archived data gathered during an ethnography of IDEO, a product design firm. This firm exploits its network position, working for clients in at least 40 industries, to gain knowledge of existing technological solutions in various industries. It acts as a technology broker by introducing these solutions where they are not known and, in the process, creates new products that are original combinations of existing knowledge from disparate industries. Designers exploit their access to a broad range of technological solutions with organizational routines for acquiring and storing this knowledge in the organization's memory and, by making analogies between current design problems and the past solutions they have seen, retrieving that knowledge to generate new solutions to design problems in other industries. We discuss the implications of this research for understanding the individual and organizational processes and norms underlying technology and knowledge transfer more generally.•

Knowledge is imperfectly shared over time and across people, organizations, and industries. Ideas from one group might solve the problems of another, but only if connections between existing solutions and problems can be made across the boundaries between them. When such connections are made, existing ideas often appear new and creative as they change form, combining with other ideas to meet the needs of different users. These new combinations are objectively new concepts or objects because they are built from existing but previously unconnected ideas. This paper presents an ethnographic study of a product design firm that routinely creates new products by making such connections.

The role these connections can play in the innovation process is evident in inventions by Thomas Edison's laboratory. Edison and his colleagues used their knowledge of electromagnetic power from the telegraph industry, where they first worked, to transfer old ideas that were new to the lighting, telephone, phonograph, railway, and mining industries (Hughes, 1989; Millard, 1990). Edison's products often reflected blends of existing but previously unconnected ideas that his engineers picked up as they worked in these disparate industries. The phonograph blended old ideas from products that these engineers had developed for the telegraph, telephone, and electric motor industries, as well as ideas developed by others that they had learned about while working in those industries. Edison's inventions were not wholly original. Like most creative acts and products, they were extensions and blends of existing knowledge (Merton, 1973). As Usher (1929; quoted in Petrovski, 1992: 44) argued, "invention finds its distinctive feature in the constructive assimilation of pre-existing elements into new syntheses, new patterns, or new configurations of behavior."

Social network theory suggests that Edison's laboratory could innovate routinely because it occupied a "structural

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hole'' (Burt, 1992a, 1992b), a gap in the flow of information between subgroups in a larger network. For Edison, these gaps existed between industries where there was and was not knowledge about the newly emerging electromagnetic technologies. Actors filling these gaps are brokers who benefit by transferring resources from groups where they are plentiful to groups where they are dear (Marsden, 1982; Gould and Fernandez, 1989; Burt, 1992a; DiMaggio, 1992). Brokers have an advantage over competitors because ''nonredundant contacts are linked only through the central player, [so brokers] are assured of being the first to see new opportunities created by the needs in one group that could be served by skills in another group'' (Burt, 1992a: 70). Edison's laboratory acted as a broker of technological ideas because it had connections to many industries, rather than being central in one, and it linked industries that had few other ties (DiMaggio, 1992).

By highlighting the structure of resource flows across group boundaries, researchers have shown that brokers benefit from disparities in the level and value of particular knowledge held by different groups, but they have not explicated the process by which information is transformed or combined within these flows. Valuable solutions seldom arrive at the same time as the problems they solve, they seldom arrive to the people working on those problems, and they seldom arrive in forms that are readily recognizable or easily adaptable. Edison's laboratory did more than just transfer knowledge from groups where it was plentiful to groups where it was dear; this organization acquired such information, stored it, and retrieved it to create new combinations of old ideas. Walsh and Ungson (1991: 61) described these processes (i.e., acquisition, retention, and retrieval) as routines supporting an organization's memory, which they defined as ''stored information from an organization's history that can be brought to bear on present decisions.'' This perspective suggests that a technology broker depends on both its network position as a broker and on an organizational memory that allows it to acquire, retain, and retrieve new combinations of information obtained through such a position.

The notion that brokers transform and blend information is implicit in DiMaggio's (1992) description of how Professor Paul Sachs used his strong connections to the previously weakly connected worlds of museums, universities, and finance to help create New York's Museum of Modern Art. This notion is also implicit in writings on technology transfer (Rosenberg, 1982, 1994; Rogers, 1983), which recognize that existing technologies are often adapted and transformed before they become usable in a new field. But these writings do not focus on the role that individual actions and organizational routines play in recognizing, storing, blending, and transforming those technologies to make diffusion possible. Except for Attewell's (1992) description of how consultants facilitated the diffusion of a business computing technology, we don't know of any empirical or conceptual work that weaves together macro perspectives on external networks with micro perspectives on internal routines to describe the role of brokering in innovation.

This paper develops such an integrated perspective in a process theory of how one product design firm acts as a technology broker. Following Weick's (1992) approach to theory building, we develop a relatively full explanation of brokering in a small region, which is then used to guide general discussion about brokering in other settings. We use an ethnography of a product design consulting firm to develop a local theory of how this organization acts as a technology broker. This firm has designed products for several hundred different firms in over 40 industries, ranging from pagers to closet-size medical analysis products. The quantity of new product designs (the firm works on between 60 and 80 products at a time), together with the tangible nature of the mechanical solutions that usually make up those designs, allowed us to observe how this firm recognizes, blends, and transforms existing ideas into new and innovative combinations. By having strong connections to many industries but not being central in any one, the engineers in this firm have constant opportunities to learn about technologies from a broad range of industries. The firm exploits its network position with internal routines that help its designers create products for current clients that are new combinations of existing individual technologies that these designers have seen before. Many of these products reflect the transfer of ideas to industries where they have not been used before and the creation of combinations of ideas that no one in any industry has seen before.

METHODS

Research Setting

This ethnography was conducted at IDEO, the largest product design consulting firm in the United States.[1] IDEO was co-founded by the current CEO David Kelley in 1978. It employs over 125 designers who develop products for other companies. Headquarters are in Palo Alto, California, with smaller offices in Boston, Chicago, Grand Rapids, London, San Francisco, New York, and Tokyo. The bulk of IDEO's work is in mechanical engineering and industrial design. Mechanical engineers design products for physical performance and ease of manufacturing; industrial designers use artistic skills (with an appreciation of engineering) to design products that are attractive and easy to use. Our study focused on the 45 or so engineers in Palo Alto who do mechanical engineering and (to a lesser extent) electrical, software, and human factors engineering and on the 35 or so managers and staff who support their work. We follow our informants' usage and describe IDEO's engineers as "product designers" or "designers" most often, but we (and they) sometimes use "engineers." Most designers are 25 to 40 years old, male (about 80 percent), white (about 80 percent), and usually have a B.S. or an M.S. in engineering. Managers have a similar profile but tend to be older (35 to 50 years old). Support staff also have a profile similar to designers, but a higher proportion (approximately 50 percent) are women.

Clients typically hire IDEO to design part or all of a product that they would like to manufacture and sell but lack the expertise or staff levels to design. Clients range from *Fortune*

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Sutton and Hargadon (1996) also used this ethnography as the basis for a paper on the effectiveness of brainstorming sessions. That paper contains additional information about the research setting for this ethnography and the methods used, as well as about IDEO's structure, work practices, norms, and values.

50 to start-up companies. IDEO usually charges clients for the time and materials required to design a product but occasionally works in exchange for a percentage of sales or profits from the finished product. Design projects last from a few weeks to three years, with an average of about a year. Results range from sketches of product concepts to crude working models, to complete new product designs. IDEO has contributed to the development of over 3,000 products. Widely known products include the original Apple computer mouse, a Microsoft computer mouse, Smith ski goggles, AT&T telephones, Oral-B toothbrushes, Crest toothpaste tubes, Steelcase furniture, Sega game controllers, Hewlett-Packard printers, rechargers for General Motors' electric vehicles, laptop computers for such firms as Apple Computers, Dell, and NEC, the Macintosh DuoDock, Regina vacuum cleaners, and a life-sized, functioning, mechanical killer whale used in the film "Free Willy." Less widely known products include surgical skin staplers, a combination beach chair and cooler, a coin sorter, a blood platelet function analyzer, a toy guitar, and the Enorme telephone. IDEO is widely praised in the business press for its innovative designs; for instance, IDEO won more *Business Week* Design Excellence Awards in 1993, 1994, and 1995, and over the last decade, than any other product design firm.

Method

Each of the two authors spent six to eight hours per week doing an ethnographic study of IDEO from March 1994 through May 1995. Fieldwork continued at a less intensive level through February 1996, with at least one of us visiting IDEO each week. We wrote field notes after each visit or meeting. Each of us also visited IDEO at least once a month through December 1996, often to collect more evidence or to check the accuracy of facts that appear in papers about IDEO. Any visit to IDEO entailed unplanned conversations, because many engineers, support staff, and managers were curious about our research and because IDEO norms support friendly talk about the firm and the design process. The buildings where most design engineers work have a modified open-office plan, which further encourages informal talk. In addition, most IDEO buildings in Palo Alto (industrial design, administrative offices, two machine shops, and a joint venture with a large corporation) are on the same street and within a few blocks of one another, so many unplanned but enlightening conversations occurred as we walked between buildings.

We began this ethnography with a vague research question: How does IDEO innovate routinely? Although we often interacted with senior managers during these visits, our data collection focused on watching and talking to product designers and looking at and gathering the drawings and physical artifacts that resulted from their work. We adopted this focus because our primary aim was to understand how people do and experience innovative work, not how it is viewed by management or support staff. Following guidelines for inductive research, we were as descriptive as possible until major themes emerged from the data (Glaser and Strauss, 1967; Miles and Huberman, 1994). When a promising theme like technology brokering emerged, we focused data collection on it, read pertinent literature, and did preliminary analyses to decide if it was worth pursuing. Our interest in brokering was sparked in the winter of 1995 when we noticed that designers offered solutions to new problems by describing similar solutions they had seen in past products, a process they called "cross-pollination."[2] The evidence guiding our descriptions of and inferences about technology brokering at IDEO is divided into seven general categories:

1. Tracking development projects. Each of the two authors followed a development team as it designed a product. We met with team members about once every two weeks, attended design meetings, and were given sketches, reports, and videotapes. The first author followed a team for four months until it nearly finished designing a Regina vacuum cleaner. A new CEO stopped work on this prototype and other designs being done by and for Regina to reevaluate the firm's product strategy. About six months after we stopped tracking the team, Regina decided that IDEO should finish the design, and the product was completed, manufactured, and sold. The second author followed a team for six months while it worked on personal appliances. He followed this team until two prototypes and detailed drawings were completed. These completed designs were not manufactured and sold because the firm changed strategic direction after it was acquired by a larger corporation and the CEO stepped down.[3]

2. Semistructured interviews with designers and managers. We conducted 60 semistructured interviews; 37 were tape-recorded and transcribed; we took notes during others. We had multiple interviews with some informants, so approximately 35 people were interviewed. In initial interviews, we asked senior managers and designers general questions about IDEO's history, clients, competitors, structure, human resource practices, and work process. Subsequent interviews focused on themes like technology brokering that we wanted to learn about in detail.

3. Informal discussions. We had hundreds of informal conversations with managers, designers, and support staff, ranging from brief exchanges to long talks over lunch. We talked with almost every employee at the Palo Alto headquarters and had dozens of conversations with the CEO. We also had informal conversations with ten IDEO clients about the company. The content varied widely, with designers often gossiping about new clients, employees who had been hired or had left, the virtues or drawbacks of current IDEO prototypes, "cool" new technologies that they had seen or heard about, or why they loved or despised existing products, ranging from toy Slinkies to Harley-Davidson motorcycles. In addition, after we began asking questions about emerging themes, including technology brokering and brainstorming sessions, designers often approached us with comments, questions, stories, prototypes, and sketches that they believed would enhance our understanding of these topics. Conversations with clients were equally diverse, but at least three of them talked with us about technology brokering. For example, one client described how IDEO designers had introduced his organization to promising technical

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Various versions of this paper have been described to and read by IDEO designers and managers since our ethnography ended in March 1996. This conversation and reading has led some designers to adopt the term "technology brokering" as a synonym for "cross-pollination."

3
The technological details of the products and projects we observed at IDEO are critical to presenting a theory of technology brokering. For reasons of client confidentiality, however, we have had to disguise approximately 10 percent of these products. In doing so, we substituted products of similar technological complexity and confirmed these selections with the designers who were involved in the original projects.

solutions that were new to that industry but were used widely elsewhere.

4. Brainstorming sessions. We observed 24 group brainstorming sessions in which products were designed, six in person and 18 on videotape. Each meeting was initiated by members of a design team. They invited IDEO designers who were not team members to generate possible design solutions for the project. IDEO brainstorms are scheduled meetings and are held in conference rooms. Five brainstorming rules are displayed in large letters in several locations in each room: (1) defer judgment; (2) build on the ideas of others; (3) one conversation at a time; (4) stay focused on the topic, and (5) encourage wild ideas. IDEO's *Methodology Handbook,* which outlines IDEO's techniques for new designers, contains 11 pages of instructions about how to facilitate and participate in brainstorms. Designers who lead brainstorms are skilled and experienced facilitators; nearly all IDEO designers have extensive experience as participants in brainstorms.

The sessions we observed lasted between 45 minutes and two hours. The topics ranged widely: three about personal appliances, three about furniture, three about video cameras, two about surgical skin staplers, two about medical devices to aid healing, two about blood analyzers, two about laptop computers, two about personal communication, one about remote controls, one about ski goggles, one about vacuum cleaners, one about faucets, and one about a portable traffic control system. Typically, project engineers introduced the project and described a design problem they were facing, then the other engineers offered possible solutions, often in the form of solutions they had seen in other settings. Solutions were sometimes found in similar products that were brought to brainstorms (e.g., a designer suggested adapting a design solution for a new skin stapler that was already used in a competitor's product) or in products that were brought in from different industries (e.g., a designer showed how a gas engine from a model airplane could be used to power a skin stapler). Designers also described and sketched solutions on paper or on whiteboards in the room. The visible and vocal nature of these meetings offered us the opportunity to observe how new problems and existing solutions were shared among the designers.

We wrote field notes about each brainstorm and were given "brainstorming reports" for nine of the 24. These reports are prepared for the client by the brainstorm organizers; they summarize the ideas generated and develop promising ideas in greater depth. We also distributed a short survey about product design brainstorms at IDEO to engineers in the Palo Alto office. We distributed 45 surveys, and 37 were returned; 27 included written comments. This survey contained 40 closed-ended questions, but in this paper we only use written comments that designers made in response to a request for "any other comments about brainstorming at IDEO." See Sutton and Hargadon (1996) for a more extensive discussion of brainstorming at IDEO.

5. Other meetings. We attended a session about how to handle a major client, a session with that client, a meeting with IDEO engineers who studied their firm's design process, and about twelve "Monday morning meetings." Most Mondays, CEO Kelley meets with the employees in Palo Alto who do or support "engineering design." They usually sit on the floor in a circle. Meetings start with Kelley talking about pressing, interesting, or funny events and then turn to new projects and progress on ongoing projects. "Show and tell" is next, in which designers display and describe new products, prototypes, materials, and methods. We also attended and participated in three meetings about IDEO's design process. The first and second of these were brainstorming sessions on how to describe and transfer IDEO's design process to other organizations. The third meeting focused on technology brokering; experienced designers talked about how and when they had combined their diverse technical knowledge to create new products and things they did to facilitate this process.

6. Design team interviews. We did retrospective interviews with four design teams, which were tape-recorded and transcribed. The products were a label-maker, a blood platelet analyzer, a mechanical killer whale, and a furniture system. Each was a large-scale project requiring multiple engineering disciplines. Designers brought prototypes and the final product to two of the interviews. We asked the group to describe how the project unfolded and the role that each member played. We asked them to describe the technical details of the project: the prominent technologies of the final design, how these were chosen, and how each team generated and explored alternative solutions throughout the project. Finally, we asked them to describe any interpersonal and political issues that arose during the project.

7. Materials about the organization. We gathered several dozen stories about IDEO from various sources, including *Fortune, Business Week, Wired, ID, Wall Street Journal,* and popular books. We viewed approximately fifteen television programs about IDEO first shown on outlets such as ABC, CNN, BBC, PBS, and the Discovery Channel and explored a CD-ROM "tour" of IDEO. We gathered other materials produced by and about IDEO, including a *Methodology Handbook* for new engineers and sketches of prototypes. We also reviewed IDEO's collection of approximately 1,400 photographs of product sketches, prototypes, the design process (e.g., pictures of brainstorming sessions), and completed products.

A PROCESS MODEL OF TECHNOLOGY BROKERING

These qualitative data indicate that IDEO learns about potentially useful technologies by working for clients in multiple industries and finds opportunities to use that knowledge by incorporating it into new products for industries where there is little or no prior knowledge of these technologies. This design process results in the movement of technologies between industries, reflecting the technology transfer and diffusion that is recognized as fundamental to technological evolution (Rosenberg, 1982; Basalla, 1988; Hughes, 1989). Existing research has considered the social, economic, and political effects of this type of innovation, but little is known about the nuances of how such processes unfold within organizations.

Technology brokering at IDEO entails more than just transporting ideas between previously unconnected industries; it also means transforming, sometimes radically, those ideas to fit new environments and new combinations. An innovative product might contain several components that are new to the industry, blended with many old components that continue to fit the industry's needs. Brokering requires integrating these new and old technologies in ways that allow each to function well. For example, to develop the Cholestec Home Cholesterol Tester, IDEO designers combined a compact disk inject-eject mechanism, a simple software interface, and high-volume production design principles, each of which were relatively new ideas to the medical products industry, with sampling and testing components and chemical treatment technologies already used widely and fairly well understood in that industry. Designing the product required modifying both the compact disk inject-eject mechanism to fit the needs of the existing sampling technologies and modifying the existing sampling technologies to fit the capabilities of the inject-eject mechanism. Many of IDEO's product designs are, like the home cholesterol tester, new combinations of existing components that reflect Weick's (1979a: 252) definition of creativity as "putting old things in new combinations and new things in old combinations."[4] This perspective on technology brokering began to develop when, early in our study, we noticed that many of IDEO's designs contained innovative features that engineers had seen in previous products. We created a list of IDEO-designed products that included features designers had adapted from previous products, prototypes, or other sources outside of the client's industry. We met with IDEO designers individually and in groups to add to and refine this list, which is shown in table 1. It contains 30 examples of IDEO-designed products that are new combinations of old technologies taken from both inside and outside the client's industry. One example is a portable computer docking station designed for Apple Computer. It consists of traditional computer components that were combined with an insert and eject design adapted from video-cassette recorders and powered by an inexpensive motor found in toys.

Our data suggest that IDEO's ability to generate innovative products that are new combinations of existing technologies can be understood by considering both the organization's network position and the behaviors of its designers in exploiting that position. Figure 1 summarizes the relationship between network position and internal behaviors in a four-step model of technology brokering. *Access* (step 1) describes how IDEO fills a gap in the flow of information between industries and is able to see technological solutions in one area that are potentially valuable in others (Burt, 1992a, 1992b; DiMaggio, 1992). But the way these technologies become innovative solutions to current problems depends on how these potential solutions are shared within IDEO across designers and over time. The remaining three steps of the model describe the role of IDEO's organizational memory in turning technologies seen in past products into

4 This definition of creativity is not new. Schumpeter (1934: 65–66) described innovation as the "carrying out of new combinations" and Usher (1929: 11) described technological innovation as the "constructive assimilation of pre-existing elements into new syntheses." A decade earlier, Ogburn (1922; quoted in Basalla, 1988: 21) defined invention as "combining existing and known elements of culture in order to form a new element." And, even earlier, Ribot (1906; quoted in Torrance, 1988: 45), a psychologist studying creativity, maintained that creative thinking produced "unforeseen and novel combinations," but "in equal measure absurd combinations and very original inventions."

Table 1

IDEO-Designed Products that Incorporated Technological Solutions from Outside Industries

1. Water bottle: Combines existing body with leak-proof nozzle based on previous shampoo bottle design.
2. Blood analyzer: Combines existing analytic technologies with computer components: printer, keyboard, display, and circuit board.
3. Portable computer: Hinge design in portable computer display incorporates a bail mechanism found in typewriters.
4. Whale special effects: Mechanical whale combines hardware and software from the computer industry, hydraulics and robotics from designer's academic background, and latex skin and other existing special effects techniques.
5. Computer PCMCIA card adaptor: Eject mechanism combines nitinol (memory metal) from defense industry technology and existing circuit board and connector technologies.
6. Vacuum cleaner: Combines existing components with new complex plastic parts designed utilizing previous CAD experience.
7. Home cholesterol tester: Existing analytic components combined with CD inject/eject mechanism from consumer products.
8. Portable computer: Retracting foot design based on foot mechanism on slide projector.
9. Toy electric guitar: Incorporates toy industry materials and design with microprocessor technologies from previous computer projects.
10. Input device for kid's video games: Combines oversized trackball from previous computer input devices and existing toy industry components.
11. Cosmetics product: Incorporates flexible tubing from previous surgical product and vacuum technology from 2 previous vacuum cleaner projects.*
12. Bicycle helmet: Includes sailcloth strengthener from designer's sailing background as well as existing foam and shell components.*
13. Label maker: Existing label maker enhanced with interface design from computer projects and display screen, printer, input devices from computer projects.
14. Personal computer: New design for cooling computers based on design principles in ceiling fans.
15. Surgical skin stapler: Existing stapler combined with ideas from model airplane engines, office staplers, and other medical products.*
16. Original Apple mouse: Mouse design tracking mechanism adapted from giant trackball in video game machine.
17. Handheld computer: Hinge mechanism based on principles found in office binder clips.*
18. Personal computer: New computer door design based on idea from garage door via previous computer projects.
19. Tire pressure monitor and valve: Pressure gauge based on bellows mechanism found in stainless-steel fuel line product.
20. Desk lamp: Uses articulating ball-and-socket joint design taken from principles in human hip-bone sockets.
21. Portable computer docking station: Uses an eject mechanism based on ideas from video-cassette recorders, docking connectors from a previous computer docking project, and an inexpensive electric motor from toys.
22. Medical analysis product: Incorporates a solid-state fluid warmer found in portable coolers for automobiles.
23. Computer monitor: Existing monitor incorporates a clutch spring design based on idea of leaf-springs in automobile shocks.
24. Office chair spring: Seat spring combines existing seat spring components with design of rubber spring shocks used in tool and die industry.*
25. Electric car charger: Powered door opener uses gas piston from rear window of station wagon combined with electric charging components.*
26. Portable computer: Display fastened closed using bicycle spokes and existing display housing technologies.*
27. Waste paper collector: Take-up reel design based on ideas from continuous towel dispensers and typewriter printer ribbon cartridges.
28. Paper handling product: Paper tray mechanism combines parallel ruler designs in drafting boards with existing paper handling components.
29. Computer monitor: Concept for new mounting design based on "Monkey-on-a-tree" toy.
30. Slide printer: Motion control solution based on stainless steel, zero backlash motion control found in early disk-drive head designs.

* The early prototypes of these products used off-the-shelf components from these different industries in testing the performance of this technological solution in its new combination. Later designs became specific to the new product, but in the case of the bicycle spokes, a local wheel manufacturer actually became a supplier of production parts for a portable computer.

useful information for designing new ones (March and Simon, 1958; Huber, 1991; Walsh and Ungson, 1991). *Acquisition* (step 2) describes routines that IDEO's designers use to bring technological solutions into the organizational memory, where they are stored for possible use in future design projects. *Storage* (step 3) describes how these solutions remain in memory until they are considered for use in future designs. Finally, *retrieval* (step 4) describes how designers retrieve some of these old technological solutions from the organizational memory in forms that fit the new combinations they are creating.

This process model presents access, acquisition, storage, and retrieval as linear and distinct phases. We use this model because it fits our data reasonably well and provides a simple and analytically useful way of summarizing these data. Nonetheless, the process was not always as neatly linear as the model implies and the steps could not always be cleanly distinguished. As Walsh and Ungson (1991: 82) recognize, "Because the acquisition, retention, and retrieval of memory is an ongoing process, it is difficult to pinpoint the exact boundaries between these processes."

We used an iterative process to develop the inferences about the process of innovation through technology brokering at IDEO that are summarized in figure 1. Following Glaser and Strauss (1967) and Miles and Huberman (1994), a set of iterations usually began with a hunch inspired by the data or literature (e.g., an informant mentioned that the original idea for a water bottle valve came from another designer who had worked on a previous shampoo bottle project, which suggested that ideas from different industries provided IDEO with potentially valuable solutions in later projects). Then, to see if a hunch could be grounded, we compiled pertinent evidence from all seven data sources (e.g., we looked for evidence that IDEO's experience in a range of industries provided its engineers with useful ideas). These analyses led us to abandon, modify, or maintain each inference (e.g., we retained the inference that access to a range of industries was an important aspect of IDEO's innovation process). If the inference was retained, we summarized the grounding for it in a within-site display reflecting how strongly each inference could be grounded in each data source. We then wrote up our inferences about each retained consequence, weaving together conceptual arguments, additional evidence, and citations to pertinent literature. Table 2 presents the evidence that grounds our process model of technology brokering.

Access: IDEO'S Network Position as Technology Broker

Brokers derive value by enabling the flow of resources between otherwise unconnected subgroups within a larger network (Marsden, 1982; Gould and Fernandez, 1989; Burt,

Figure 1. A process model of how innovation occurs through technology brokering.

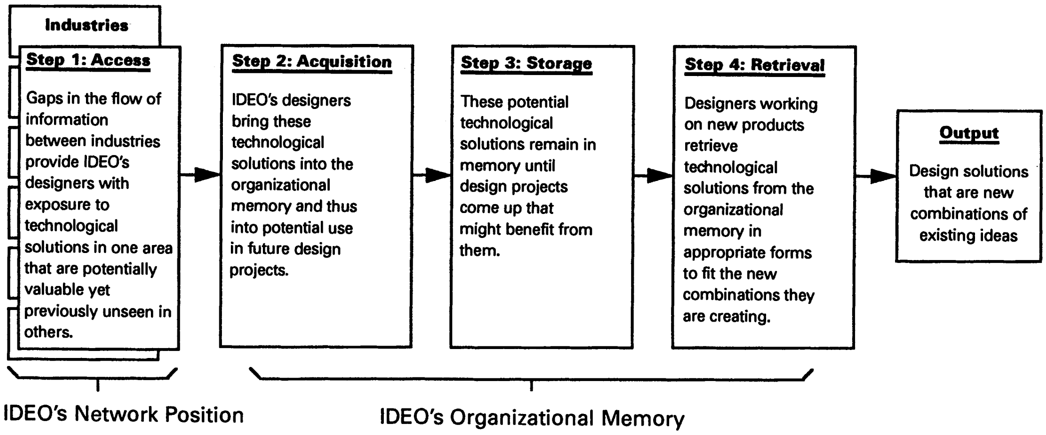

Table 2

Evidence Supporting the Process of Technology Brokering at IDEO*

Process	Tracking design teams	Semistructured interviews	Informal discussions
Access: Access to technological information in one area that is potentially valuable yet previously unseen in others	Sporadic evidence One design team was working on a vacuum cleaner design, the other on a product for personal cosmetics. Designers on each team had previously worked on medical products, computer projects, telephone headsets, and trackball devices.	Strong evidence Most designers interviewed stressed IDEO's range of clients and industries. Another designer mentioned that most of them had hobbies that cross-pollinated their designs. Ideas from model airplanes would work their way into portable computer designs.	Moderate evidence CEO talks about having clients in every industry: "you name an industry—Vacuum cleaners, washing machines, or pagers [and we've been there]."
Acquisition: IDEO's designers acquire technological solutions for possible use in later projects	Strong evidence "The best way to come up with ideas is first of all to go out and look at what's out there. So, look at the existing products, rip them apart . . . then it's looking for peripheral objects, toasters, blenders, and mixers." "We become as much of an expert [on the client's technologies] as we can in a short period of time."	Strong evidence "[the variety of industries and products] makes you more confident that you can use something you learned in this area and move from there." "[Clients] come in with a new technology and want to apply this technology and we have to come up to speed on that particular technology so the excitement of keeping up on the learning process is there."	Moderate evidence Designers talked about gaining "a big pile of tools" from their experiences in multiple industries, and how they collected many of them, when possible. One even described his "magic box of neat stuff" that stored all sorts of little interesting technologies like nitinol, velcro, high-strength alloys, etc., that he had acquired in his past projects and hoped to be able to use later.
Storage: Potential technological solutions remain in memory until design projects come up that might benefit from them	Strong evidence One designer kept a box of existing motors, hinges, joints, etc., that served as a "build-everything kit" from which he created prototypes for new projects. "[When you've developed knowledge about a particular field] there's no question that you're a resource."	Strong evidence The cubicles of individual designers were often filled with dozens of products they had worked on, models they had built, toys, and pictures of interesting products. "People know each other and they know who to ask. . . ." "The model is you become a real expert and you're recognized [around] the company as being an expert in that particular field."	Strong evidence Wandering around halls and offices we could see enormous collections of products, toys, and models. Designers would refer to people as experts in particular fields or technologies: one who knows about mechanisms, another about materials.
Retrieval: Designers working on new products retrieve old technological solutions from IDEO's memory in appropriate forms to fit the new combinations they are creating	Strong evidence In one case they took parts from a previous vacuum project and glued them into a new hair dryer of their own design to test the combination. "[You get help from other designers by] planting these seeds all over the place and . . . the wider you can plant it the more stuff that keeps coming in." "I just send an e-mail to 60 engineers . . . and one of them knows the answer and gets back to you within minutes. . . ."	Strong evidence "I especially love Japanese toys, but good toy design, because we bring them out in brainstormers and apply the ideas to skin staplers or mechanisms, whatever." "There's often things that people need help on, they put them on e-mail and there's almost always responses."	Moderate evidence Designers talked about cross-pollination: they feel like they are bringing good ideas from one product to another. Many of the designers emphasized the importance of brainstorming, electronic mail, and informal sharing of ideas.

* Strong evidence = a dominant theme in this data source that is consistently supported; moderate evidence = a frequent, but not constant theme in this data source that is consistently supported; sporadic evidence = a theme that appears now and then in this data source and is consistently supported.

Table 2 (*Continued*)

Other meetings	Design team interviews	Written material and videos	Observed brainstorms
Moderate evidence Current projects are discussed at each Monday meeting, including computers, fishing gear, keyboard supports, office systems, and bicycle wheels.	Moderate evidence Interviews were with design teams that had recently completed products in the medical industry, computer network communications, movie special effects, and a label maker for the typewriter industry.	Strong evidence Lists of clients show a range of industries. "Working with companies in such dissimilar industries as medical instruments, furniture, toys, and computers has given us a broad view of the latest technologies, materials, and components available."	Sporadic evidence Designers learn about new industries when clients or project leaders introduce technological problems in question and answer sessions lasting from 5 to 25 minutes at beginning of each brainstorming meeting.
Moderate evidence In the Monday meetings designers pass around parts they found that are good examples of manufacturing technologies, new products, or prototypes, for example, a co-injection molded plastic and rubber handle for a drill. These parts make their way around the room, and every designer looks at them, inside and out, with interest.	Moderate evidence One project team explained that "the first thing we do is, we [brought] a lot of different label printers, one of each, from Brother, from Casio and so forth [in an effort to learn about the industry]." "As always, there is the technical learning going on, so, that was the good part [about this project]."	Strong evidence "As consultants we need to quickly become experts in the client's product area. . . . We need to orient ourselves to the major pitfalls, alternatives, and opportunities." "The designers here become pretty flexible and fast on their feet, and they enjoy going from toy guitars, to microwave repeaters, to laptops, to anything."	Strong evidence One principal in the firm described a "technological awareness" that made IDEO's designers aware of many existing technologies and able to recall them later to solve particular design problems. As people brought in products and parts of products, all of the designers would begin to play with them and learn about them.
Moderate evidence In the Monday meetings designers learn about what others are doing as they pass around parts they found that are good examples of manufacturing technologies, new products, or prototypes. In addition, a large part of every meeting focuses on current projects, with each of the major project teams discussing what is going on and what they are doing or learning.	Sporadic evidence Designer would talk about buying and taking apart competitor's products. One team talked about the talents various designers brought to the project: manufacturing expertise or previous related experience in the design of medical disposables.	Strong evidence "Prototypes of all kinds of machines and in all stages of development literally litter the place." *Methodology Handbook* advises designers to "become an expert in the product area: learn everything that's out there." "Somebody is always running off to get something—a piece of hardware, a tool, a model, some materials, etc. . . ."	Moderate evidence One designer dumped on the table a box of 20 television remote controls from a previous project. The designers looked at these while generating ideas about a new "television navigation system." A designer put on the table pieces of IDEO-designed children's furniture to illustrate a particular material to use in a kitchen table design.
Sporadic evidence In Monday morning meetings, the evidence is mostly implicit: designers pass around examples from vendors or from interesting products to make everyone aware of these ideas. They also talk about the current status of their projects, including problems they are facing. Problems and solutions discussed in these meetings would often lead to later discussions one on one.	Sporadic evidence Designers mentioned holding brainstorming meetings to solve particular problems or bringing in outside consultants as experts in particular areas.	Strong evidence "It's valuable to get people to pull in bits of hardware, like having a bunch of squirrels going out and gathering things. You see these active minds making the connection." "When you get a lot of people thinking about the issues, you multiply the chances that somebody will come back with an idea or article that's pertinent."	Strong evidence "[The key to a good solution is to] get tons of related hardware in the brainstorm." A brainstorm report on "designing the future's TV remotes" lists 65 analogies to products or ideas. "Brainstormers are useful in getting detailed knowledge about your project out so it stimulates others to suggest solutions or offer leads that a simple e-mail message might not."

1992a; DiMaggio, 1992). Marsden (1982: 202) defined brokers as intermediate actors that "facilitate transactions between other actors lacking access to or trust in one another." Considerable network analytic research has shown the power that accrues to brokers. Fernandez and Gould (1994) showed that organizations occupying brokerage positions in the national health policy domain were more likely to have greater perceived influence. Padgett and Ansell (1993) explained the rise to power of the Medici family in fifteenth century Florence as the result of a network position spanning otherwise unconnected subgroups. Burt (1983, 1992a, 1992b) described how the value of connecting different subgroups depends on the relative lack of other ties between those subgroups. By restricting the flow of information between subgroups, this lack of ties creates disparities in the knowledge held by the different subgroups and enables brokers to profit by providing access for each subgroup to the ideas of the larger network. Such a disconnected network structure allows brokers to benefit because they "are well connected in several networks, rather than extremely central in just one" (DiMaggio, 1992: 130). When the ideas are technological solutions, brokers benefit by being well connected to a range of disparate industries and enabling the flow of existing solutions between those that have such knowledge and those that do not.

Social network theory describes networks of individual or organizational actors and the relationships between them. Within these networks, subgroups bound sets of actors that "know one another, are aware of the same kinds of opportunities, have access to the same kinds of resources, and share the same kinds of perceptions" (Burt, 1983: 180). Another network perspective, actor network theory, has emerged from studies in the social construction of technology and presents networks as comprising not only actors but also the physical artifacts and concepts with which those actors relate (e.g., Callon, 1980; Latour, 1987; Law, 1987). The relationships of this more diverse network arrange physical artifacts, individuals, and concepts into complex organizational and technological systems. Just as organizations comprise networks of actors, products become "networks of juxtaposed components" (Law, 1987: 113). This expanded definition of network elements may more accurately reflect the technological environment that IDEO designers face, where information about existing solutions resides within the artifacts themselves, and brokers need not have close ties to other actors to access that information. For example, in one project we followed, designers learned as much about designing a new consumer product by studying the existing (and related) products as they did from talking to the client.

Subgroups in this expanded network, then, reflect relatively isolated sets of actors, technologies, and concepts. The boundaries between these subgroups can exist at many different levels, between individuals, organizations, or industries; we chose to draw them between industries because technologies most clearly emerge and evolve within particular industries yet may have potential value in other industries (Basalla, 1988; Hughes, 1989).[5] The transfer of potentially valuable technologies to other industries, when it occurs,

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Evidence suggested that IDEO also brokered technological solutions between groups within client organizations (as one informant described, "we take your watch and tell you what time it is") and organizations within a single industry (though IDEO is careful to avoid intellectual property issues). We focused on brokering between industries, however, because conceptually and empirically it offers the clearest perspective on the process of technology brokering.

can cause significant economic and competitive changes (Schumpeter, 1934; Rosenberg, 1982), but gaps in the flow of information across industry boundaries often prevent this diffusion. Organizations like IDEO, by occupying positions within multiple industries, may bridge these gaps.

IDEO's access to outside industries offers an advantage to clients who want new product innovations. IDEO's designers have generated part or all of over 3,000 new product designs for clients since its formation in 1978. They have worked most heavily in the personal computer, medical products, and office furniture industries and have also designed products for the toy, telephone, automotive, movie, ski, bicycle, printer, and video game markets. IDEO does not maintain a database of clients by industry, but our research indicates it has worked in over 40 industries. From these industries, IDEO's designers have typically seen a broader range of technologies than clients with experience in only one or a few industries. The network concept of range describes the extent to which an actor contacts a diversity of other actors and can be measured in two ways, as volume of contacts or as quality of contacts (Burt, 1983). Volume measures the total number of contacts an actor has; quality measures the extent to which an actor's contacts provide nonredundant information and support. The evidence summarized in table 2 suggests that IDEO's value as a technology broker depends not only on the number of clients and industries it works with (volume of contacts), but also on the technologies in those industries that are potentially valuable yet previously unknown in others (quality of contacts). IDEO's *Methodology Handbook* recognizes this value: "Working with companies in such dissimilar industries as medical instruments, furniture, toys, and computers has given us a broad view of the latest technologies, materials, and components available."

Access to dissimilar industries also describes Edison's laboratory in West Orange, which consulted to diverse clients. Millard (1990: 48) described Edison's simultaneous pursuit of electrical products for clients in multiple industries: "The extensive contract research carried out by the laboratory staff opened up new areas of investigation and offered valuable spillovers of information that Edison was waiting to exploit." Millard (1990: 68) cited an example of this spillover in Edison's work for different clients in sound recording and in telephones, both of which required technical knowledge about acoustics: "The experiments in reproducers [for recording] were paralleled by the continuing work on telephone transmitters and receivers; as usual he was hoping that one series of experiments might turn up some information useful in another." Millard (1990: 48) also implicitly recognized the value of such access when he described the purpose of Edison's laboratory: "to bring together flows of information at the right moment, providing the basic raw material for the invention factory."

Like Edison's laboratory, IDEO has access to dissimilar industries that enables it to generate new product innovations through technology brokering. In one case, a blood analyzer was originally designed to be controlled by a separate personal computer. IDEO's designers instead used their previous experience designing such computers to incorporate the necessary features—a circuit board, printer, keyboard, display screen, and software interface—into the product. The result was a new and more integrated blood analyzer that represented a relatively dramatic combination of existing solutions in computer and medical product technologies. Brokering also provides innovative solutions to more common design problems. For instance, when designers became aware that a portable computer display lacked the room necessary for traditional fasteners, they developed a solution using modified bicycle wheel spokes as fasteners. In both of these examples, IDEO's designers were able to bring together technologies from within and outside of their client's industry to generate innovative new products and solutions.

IDEO's *Methodology Handbook* recommends that designers "look for opportunities to expand IDEO's network and/or industry knowledge." This may be more easily done now that IDEO is relatively large and already well connected in a range of industries and thus has something to offer other clients. When IDEO was a small start-up company, access to disparate industries and technological knowledge was serendipitous. IDEO has its roots in the Silicon Valley and the computer industry, and one of the early IDEO employees described their original advantage: "At the time we were really naive, but our customer base, when we all just started, was just as naive. So, we knew just enough to be ahead of them and it worked pretty well. They were all electrical engineers and software guys. They didn't know anything about mechanical engineering or making things, and we knew just enough to be able to be useful to them." As the Silicon Valley and information technologies developed, IDEO was able to continue creating innovative products by designing the mechanical and electromechanical components surrounding the new information technologies as they diffused to other industries. CEO David Kelley described this strategy as "being the high-technology company to low-technology companies." And as IDEO's connections to different industries grew, designers gained experiences with many other technologies and have provided their clients in the computer industry with useful technologies, such as low-cost electric motors, new hinge designs, or new materials that were taken from these other industries.

Technology brokering is visible at the level of firms and industries, but it takes place through the actions of teams and people. IDEO's contact with different technologies comes through the individual engineers' contact with the industries where those technologies are used. For industries in which IDEO has multiple clients, such as the computer industry, many designers have worked with and understand the technologies involved. For industries in which fewer engineers have participated, such as surgical instruments, only a few might be familiar with the prevalent technologies. Designers also come into contact with potentially valuable solutions through the technical training and jobs they had before coming to IDEO and through their hobbies and personal backgrounds. IDEO has hired particular designers, in part, because of their past experience in and knowledge of medical products, manufacturing, and disk drives. In addition, IDEO hires designers for their knowledge and interest in areas outside of their work, such as toys, bicycles, model airplanes, sailing, sculpting, farming, woodworking, music, opera, cars, motorcycles, skiing, and mountain climbing. The broad knowledge and interests of IDEO's engineers result in access to design solutions beyond the solutions that IDEO is exposed to in its clients' industries.

Most social network analyses measure current social relations between actors. In contrast, because an engineer's knowledge of potential solutions represents past as well as ongoing relations, his or her network ties to a range of industries accumulate over time. As a result, each engineer has a distinct body of technological knowledge from working with IDEO clients, from past technical training and work experience, and from his or her personal interests and backgrounds. The role this diverse knowledge plays in creating new products is evident in a description of how one designer's personal background was the source of new solutions:

> Everybody seems to have a couple of kinds of interesting backgrounds. Fred—because he used to build model airplanes—was very good at it. Model airplanes have all these swivel and control things, and he'd bring all this kind of technology to our prototypes: little brass tubes and all these little hinges. He knew all that was possible, and he would have a bunch of stuff in his garage and he'd bring that in and we'd make prototypes out of it. Other people are into a lot of stuff. The technology of bicycles, which is actually quite developed and refined, can be applied to so many things. People have a universal love of toys here and I think I'm the epitome of that. Toys have so many neat things to offer. They are high volume, mass production, often plastic, and very clever because they're so cheap. I especially love Japanese toys. We will bring 'em out in brainstormers and kind of apply the ideas to skin staplers or mechanisms, whatever.

At IDEO, designers view their community as a valuable clearinghouse for technological solutions that they have accumulated through years of access to dozens of industries. In their words, this community experience allows them to "cross-pollinate" their ideas between products and industries. A network perspective describes how IDEO is able to exploit this cross-pollination in its innovation process by describing the structural conditions that allow an actor linking otherwise disconnected domains to have access to ideas that are potentially valuable, but unknown, to others. Yet while this network perspective is necessary to explain the conditions that make technology brokering possible, it is not sufficient to explain how the innovation process occurs through brokering. Much of this creative process occurs within the firm. Solutions rarely come to the firm at the time they are needed, to the people who need them, or in the exact forms necessary to solve the problems designers face. To understand how designers at IDEO make connections between existing solutions and new problems over time and across people, we need to look within the firm at the routines that designers and teams use to create new products by learning of possible solutions, remembering them, and retrieving them in new forms that fit in new combinations.

Acquisition, Storage, and Retrieval: IDEO's Internal Routines for Technology Brokering

Technology brokering means that IDEO's designers solve current design problems by drawing on technological solutions they have seen in the past. This use of shared knowledge from past experiences is the focus of conceptual work on organizational memory (March and Simon, 1958; Huber, 1991; Walsh and Ungson, 1991), which refers to the means that organizations use to retain past stimulus-response information. Organizational memory becomes visible when individual members react to new demands by drawing on an organizational pool of prior responses to similar stimuli (Walsh and Ungson, 1991). Within the product development process, past stimulus-response information refers to past design problems and their technological solutions. The means by which IDEO retains these past solutions become visible in the routines its designers use to draw on this organizational pool of prior responses to solve current design problems.

There are conflicting perspectives on the role of organizational memory in innovative activities such as new product development. March (1972), Weick (1979b), and others have described its programmed responses as threats, because they increase the organization's potential for unconsciously or mistakenly invoking ingrained, but often inappropriate, behavior. Other scholars, sometimes the same scholars, have argued the opposite: that organizational memory supports organizational innovation (Cyert and March, 1963; Neustadt and May, 1986; Walsh and Dewar, 1987; Kantrow, 1987). By routinizing search activities in standard operating procedures, organizations can become more efficient at performing them. Organizational memory can also support innovation by retaining a broader range of potential responses, providing more options for organizational decision makers. March (1972: 427) asserted that "for most purposes, good memories make good choices." The tension between these two perspectives lies between the efficiency of "automatic retrieval processes" and the uncertainty that these processes will evoke responses that are "out of step with the [problems of the] present circumstances" (Walsh and Ungson, 1991: 73). Whether an organization's memory supports or undermines its ability to innovate depends on how well its past solutions—and routines for drawing on those alternatives—can be adapted to fit the problems of the present circumstances.

At IDEO, although the design problems change constantly, past knowledge remains valuable if designers can recognize similarities between old solutions and new problems. IDEO's network position provides its designers with access to a range of disparate industries. This vantage point enables designers to see a continuing stream of new problems to which their old solutions apply and a continuing stream of new (to IDEO) solutions that may be useful for future problems. IDEO's organizational memory provides the link between these solutions and problems, and thus between industries, by providing search routines for generating a range of alternative responses based on past experiences. IDEO's organizational memory can be described with the three fundamental processes presented by Walsh and Ungson (1991): acquisition, retention, and retrieval of information from the past.

Acquisition. Access to a wide range of industries has brought IDEO's designers into contact with a wide range of technological solutions; the acquisition process brings these solutions into the organizational memory for possible use in current and future designs (Walsh and Ungson, 1991). IDEO designers acquire these solutions by talking to and watching new clients and others in the industry, by reading about the industry, by looking at and taking apart products in and related to those in the industry, and, finally, by designing products for that industry.

Most projects at IDEO begin with clients describing their existing products and their desires for the new product. IDEO's *Methodology Handbook* says: "As consultants we need to quickly become experts in the client's product area. We want to acclimate ourselves to the market, the buzz words, the competition. We need to orient ourselves to the major pitfalls, alternatives, and opportunities." This expertise helps IDEO designers to understand and work with a client's existing technologies. This ongoing process of learning from clients started in IDEO's early days and remains part of all projects. A senior designer recalled:

> We were learning as we went. If we didn't know how to do something we would never say to the customer, "we don't know how do that!" We would learn how to do it either on the job from people within the customer's company or just by going out and finding out about the stuff. Now, given our experience, there's probably very little about standard manufacturing processes that we don't know. But we still have the spark coming in because clients come in with a new technology and want to apply it and we have to come up to speed on that particular technology. So the excitement of keeping up on the learning process is there and there's also the excitement that you get when you hire younger engineers who don't have the experience and they come up to speed very quickly on this mass of information.

IDEO's engineers keep "a mix of new technology coming in from the customer side" by actively searching for the potentially valuable technologies of new industries. Knowledge of these technologies resides in more than just the clients that approach IDEO, so designers also look to industry consultants, users, and suppliers as sources of existing knowledge. In one project we followed, the design team talked about how much they learned when they flew to Los Angeles to meet with an expert on the intricacies of the materials and physics involved in the project. On another project, designers hired an outside consultant, who they described as an "electromagnetic interference guru," to help them with the design of a new computer. A project to improve the 15-minute oil change offers a typical scenario:

> Our approach was to understand what's going on, to understand and observe. So we talked to the president of the client company to see what is going on. The clients indoctrinated us into the new tune-up procedures. We talked to the head trainer, the woman who does training for all the trainers that are training the mechanics and that give demonstrative tune-ups. We talked about all the design methodology and guidelines for those types of products. We went to visit the training [center] and just watched and observed the en-

tire process. We went to some shops, watched cars being worked on, talked to managers, looked in the back rooms. We went to training seminars. We just absorbed as much as we could as an objective outsider. . . they gave us all their tools and they gave us engine dummies, and so we were using the tools and doing all sorts of stuff. We were really getting familiar with what the tools were like to handle, just immersing yourself as much as you possibly can into the whole realm of it. We brought in a mechanic, we had him go through a tune-up as a group demo because we had a whole bunch of people who were going to be in the brainstorm. There were about 15 designers in the room.

The knowledge acquired during these broad industry searches was useful in this design project and may lead to innovative solutions in future projects.

IDEO engineers also acquire knowledge by studying an industry's existing products. As the quotes in table 2 indicate, designers read industry trade magazines and product catalogs. They gather all available products in the field, use and sometimes abuse them, and take them apart to find out how they were designed. We saw this approach by a team that was designing a kitchen appliance. The project manager explained: "The best way to come up with ideas is first of all to go out and look at what's out there. So, look at the existing products, rip them apart, then look for peripheral objects, like toasters, blenders, and mixers. When you find technical problems you go out, look around [some more] and walk around ripping apart possibly relevant products." Designers on this project collected over 100 appliances from the client, stores, catalogs, and fellow designers to learn all they could about the nuances and possibilities of the technologies involved.

The primary goal of these learning activities is to design an innovative product that performs as well as, if not better than, what previously existed in the industry. While much of the knowledge acquired during these activities remains in the memories of IDEO's designers after a project is completed, the act of designing that new product is also an important step in bringing working knowledge of these new technologies into the organization. Rosenberg (1982) described this experience as "learning-by-using," and Cohen and Levinthal (1994) argued that it is critical to a firm's absorptive capacity, or ability to exploit emerging technologies. In creating new products, designers acquire intimate knowledge of the limitations and possibilities of technologies beyond what they might have learned by only talking about, looking at, or reading about those technologies. In addition, project teams will often develop alternative solutions throughout the project that, while not used in the final product, represent viable alternatives for subsequent projects. In one case, a sliding door covering a computer front panel was originally modeled after a garage door mechanism. The designer built a prototype, but that design was not ultimately chosen. Another project team was looking for a similar solution and borrowed the concept from the original prototype. Again it was not chosen for the final design, but a third project team, years later, did use it and bring it to production.

To IDEO's designers, existing products serve as records of the technologies in an industry. By gathering together, studying, and ultimately designing such products while working on a specific project, designers acquire knowledge of these new technologies for use in both current and future projects. But they also constantly engage in less focused and often haphazard searches that, in addition to being fun, provide them with knowledge for future projects. These searches might be entertaining "field trips," like when designers went to an airplane junkyard to buy a DC-3 wing, to a "robot-wars" competition, and to the Barbie Hall of Fame; in each case they described the fun they had, as well as some "cool" design ideas they saw, to the rest of the company during "show and tell" at the Monday morning meeting. These searches also occur through more mundane acts, like collecting new materials, catalogs, or interesting products, or just taking a walk to the hardware store to look around, which might also yield "cool ideas" that are announced during "show and tell" or at least are mentioned during informal conversations. Designers also told us that they helped teach and grade design classes in local schools, partly because it was an opportunity to see new and interesting ideas.

Storage. Writings on organizational memory describe storage as how an organization puts away information until it is needed (March and Simon, 1958; Huber, 1991; Walsh and Ungson, 1991). At IDEO, the storage of technological knowledge became visible only as we observed the retrieval process in conversations, brainstorms, and other group problem-solving activities. From these observations, however, it was evident that much of the knowledge of potential solutions resides in the minds of the individual designers as products they had seen or used before, projects they had worked on, or technologies they had read, heard, or talked about. The evidence, summarized in table 2, indicates two types of routines at IDEO for storing potential technological solutions: routines for storing specific knowledge and routines for maintaining and refreshing that knowledge until it can be used.

Routines for storing specific technological knowledge at IDEO placed potential solutions in the memories of individual designers and in the objects and products that designers collected from their previous work. One designer grew up on a farm and, in two brainstorms we attended (one on a new faucet design and another on cleaning carpets), he offered potentially useful solutions based on technologies from tractors and combines. But designers do not consciously identify themselves with particular technological domains; this designer, for example, also offered many solutions that did not come from his farming background. Another designer talked about how his memory of design solutions was "one big pile of tools," and, while "each industry has its own set of tools, I only remember the tools, not where they came from." Designers also keep written records of previous projects, such as brainstorming reports and part drawings. We went to one meeting about flexible tubing in which another designer (who was not in the meeting) overheard the discussion and interrupted. He had faced the same problem while on a project in another industry and offered an old brainstorming report that listed the potentially relevant solutions they had found.

Designers augment their individual memories and written materials by collecting, looking at, and talking about products or parts of products, which act as records of existing technologies. Designers stockpile old products and parts in their offices and hallways or hang them from the ceiling. Sometimes these are parts and prototypes of previous IDEO design efforts that act, as one designer described, like "congealed process—a three-dimensional snapshot of the ideas of a previous project." Sometimes they are toys, collections of products from industries IDEO has previously worked in, parts and assemblies collected from vendors, or objects that reflect designers' personal interests or quirks. The shelves in one designer's office held 23 battery-powered toy cars and robots, 13 different styles of plastic hotel keys collected during trips, a battery-less flashlight powered by squeezing the handle, an industrial pump, 11 prototypes of a portable computer, 14 prototypes of a computer docking station, six competitive computers in various stages of disassembly, 15 binders from past projects, a pile of disk drives, a collection of toothpaste tubes he had designed, a toy football with wings, a pair of ski goggles he had designed, four humorous plaques awarded for past projects (e.g., "under-the-gun" award for working under pressure), a Frisbee that flies under water, and dozens of other products and parts. This designer was especially fond of toys and spent a lot of time telling us about how his toys contained useful ideas in the form of distinctive hinges, materials, molding features, or assembly requirements.

Designers routinely loaned these objects to one another for brainstorms and other parts of the design process. A group of designers took the notion of shared "cool stuff" a step further by filling several centrally located file cabinets with hundreds of "cool design inspirations." This "technology cabinet" was a collective rather than an individual good. It was started with "donations from several designers' private collections of cool stuff," and it soon became "cool" among a wider set of designers to add new "neat and strange things" and to tell other designers about what they added. One of the cabinet's self-appointed custodians told us, "every time you look in here, something new shows up." The contents include nitinol (a metal that predictably changes its shape in response to temperature changes), tiny fans and motors the size of a fingernail, magnetorheologic fluid (which changes viscosity when magnetized), samples of carbon fiber parts, an inflatable toy gorilla, and samples of flexible circuit boards, all or parts of which the designers hoped one day to use in their design projects. There are also metal cases in the cabinet so that designers can transport pertinent parts of the collection to meetings in IDEO and at client companies. There are also larger products on display, like the DC-3 airplane wing and an old Texaco gas pump placed next to a new electric vehicle charger that IDEO designed for Hughes/General Motors. A similarly diverse set of objects was evident in Edison's laboratory. Millard (1990: 15) quoted Edison as saying, "the most important part of an experimental laboratory is a big scrap heap," reflecting, Millard said, "his reliance on a well-stocked store-room and a collection of apparatus and equipment left over from previous experiments." Like Edison's equipment and apparatus, artifacts seem to lie around IDEO's offices as reminders of interesting and potentially useful technologies, patiently awaiting the appropriate problem.

The technological solutions in the minds, written records, and products of individual designers are valuable only when they can be retrieved easily for use in current projects. IDEO maintains these memories in ways that are easy to access. Displaying objects where other designers can see them makes ideas accessible, as do the constant conversations that IDEO designers have about who has what design knowledge. As the evidence in table 2 indicates, designers informally "catalog" this knowledge about one another. Informants told us that, to be valued by one's peers, it was important to establish a reputation for having expertise that is distinctive within the community of IDEO designers. The *Methodology Handbook* is explicit in this advice: "become an expert in the product area: learn everything that's out there." IDEO designers act like "gatekeepers" (Allen, 1977) who bring knowledge from the outside world into organizations. Allen's gatekeepers represented a minority of the population, but most engineers at IDEO fill this role. Each designer acts as a technology broker within the internal network of IDEO designers, bringing the experiences of his or her unique background to bear on the problems faced by other designers and being rewarded for doing so with respect from peers, more responsibility, and more interesting work. For example, one designer who had worked in the medical industry was respected for her knowledge of technologies involving fluid transportation, such as pumps, tubing, or valves. When other designers believed that such technologies might offer potential solutions to problems they faced, they would try to involve her in their project. As a designer put it: "The model is you become a real expert and you're recognized around the company as being an expert in that particular field. You can specialize in some design area like materials or motions or whatever and at least be recognized in the company as being really good at that. So, people come to you with their questions." In addition, upper-level managers serve as quasi-librarians. By knowing who had worked previously on what projects, they could often direct designers to individuals with relevant knowledge. One informant described the value of an upper-level manager: "Peter was the best 'hub' of information; he is involved in all of the projects and knows what everyone is working on." This informal reference system equates individual designers with families of technological solutions. So beyond developing his or her own focused technical expertise, each designer develops broader knowledge about which designers have which technical knowledge. This broader knowledge grows in parallel with the retrieval process in brainstorming meetings and other social interactions like Monday morning meetings, informal lunches, and company parties. Designers display their technical knowledge during these meetings and, in the process, teach others when it might (and might not) be useful to ask him or her for assistance. For example, we saw one brainstorming session lapse into a five-minute lecture by a designer on the mechanical properties of soap before the group started generating ideas again about carpet cleaning. In this way, the process of retrieval facilitates storage because it brings technical knowledge back to the surface, refreshes the memories of the individual designers, and reminds everyone else of what that designer knows.

Retrieval. Retrieval describes those routines that support the application of stored information to an organization's present decisions (Walsh and Ungson, 1991). At IDEO, retrieval entails bringing stored knowledge of potentially valuable technological solutions to bear on the design problems of current projects. As the evidence in table 2 indicates, IDEO designers retrieve technological solutions through analogic thinking and through established routines for sharing the problems of current design projects with other designers in the organization who have relevant and potentially valuable knowledge.

Technologies, in an abstract and conceptual form, carry the potential to address many different problems in many different industries. In most cases, however, designers at IDEO learn of possible technologies by seeing them in existing products, in specific forms intended to serve particular industries. To recognize the potential value of a product's technological components, the designers must abstract them from their specific, past implementation before adapting them to meet the needs of the current problem. One designer described the simplicity of the idea behind this difficult task: "If you take all the existing products or thoughts on existing products and gather them and then took the best part of each one and combined them, you'd have a better product. It is as simple as that." The way that IDEO's designers take all the existing products, recognize the best part of each one, and combine them is a critical aspect of the retrieval of potential solutions from IDEO's organizational memory. Neustadt and May (1986) argued that analogies play a critical role in organizational memory because they allow individuals to link past stimulus-response information to current stimuli. Similarly, Schon (1993) described the use of analogies, or "generative metaphors," in creative problem solving. In product design, creative problem solving draws on the organization's memory by making analogies between past technological solutions and current design problems. For example, a designer working on the hinge mechanism for the screen of a new portable computer might recognize the potential value of a hinge design that he or she had noticed holding together the wing of a plastic toy dragon. The retrieval process involves generating an analogy between this particular solution in its implementation as a toy's wing and the specific requirements of the new design problem, a portable computer.

Analogies allow product designers to see the portable computer screen momentarily as a toy dragon's wing, to view old technological solutions from a new frame of reference that allows them to recognize certain useful characteristics, such as material, design, or flexibility, and to ignore other less transferable features, such as shape, size, or original use. As a result, designers can recognize potential connections between technologies they have seen before and their current design problems. In one project, designers attempting to develop a spill-proof nozzle for a bicycle water bottle described how they recognized similarities between the problems of the water bottle design and a previous project designing a shampoo bottle that could hang upside down. In another, designers looking to power a door opener on an electric vehicle charger told us they recalled an analogous action in the pistons that open the rear window of a station wagon. In both of these examples, the ultimate solution built on the principles that were identified through these analogies, but not all analogies become part of the finished design. Designers will use analogies to generate a wide range of alternative solutions to choose from. One brainstorming session on "ways to deep-clean carpets" elicited analogies to tank treads, street sweepers, tractor combines, hair removal devices, shavers, whips, vibrating combs, squids, and Velcro (this last suggestion seems obligatory, and even humorously offered, in all brainstorms we attended). Another brainstorm, on designing a "portable kitchen counter," retrieved potential solutions by drawing analogies to jet fighter wings, plastic coolers, children's furniture, washing machines, bentwood chairs, surfboards, and skis. Elements on these lists may appear unrelated, but each analogy was used to turn aspects of existing technologies into potential solutions for the problem at hand. Analogic thinking is critical to the brokering of potentially innovative solutions because it allows for acquisition and storage of technologies in their original implementations, but for retrieval in forms adapted to the needs of the current design problem.

To recognize the potential value of a technology and adapt it to disparate products, designers must be familiar enough with a technology to generate analogies appropriate for current designs. Thus, much of the retrieval process at IDEO entails bringing designers with knowledge of potentially relevant technologies into direct contact with the problems of a new design project. Brainstorming sessions are one of the most direct ways that such contact occurs. Brainstorms are face-to-face sessions for generating ideas (Osborn, 1957); design teams convene them intermittently throughout a project. Almost all IDEO designers participate in brainstorms, which typically include six to twelve designers who are targeted for their potentially relevant knowledge in a range of technologies or industries (Sutton and Hargadon, 1996). IDEO's *Methodology Handbook* tells project leaders: "Set up at least two major introductory brainstormers to get the best minds in the company, the collective consciousness of the office, working on your problem." And a designer described what people setting up brainstorming meetings should do:

> Look for others with related expertise that might see the idea from a different perspective. The most fruitful brainstorms in these types of areas are when at least one participant has a good deal of specific, available knowledge from a different area that is still very applicable. In these cases, the client is probably unaware of this new information, and we can transfer a lot of detailed, implementable solutions.

For one brainstorm, a designer picked participants with the mix of skills needed for designing ski goggles; some knew about foam materials and their design requirements, some knew clear plastics, some knew manufacturing, and some knew skiing. IDEO uses brainstorms throughout the development process, and these meetings often bring over half of IDEO's designers into contact with a particular project.

Designers create a visually rich environment in brainstorms to help them make connections between existing product technologies and the design problems they currently face. Designers and brainstorm organizers typically bring in "tons of related hardware." One brainstorm was in a room filled with dozens of pieces from four or five vacuum cleaners plus another four assembled vacuum cleaners. A designer brought about twenty different television remote controls into another brainstorm. One designer described his preparation for brainstorms:

> When the brainstorm is on a tricky problem, I always set up what is called a crash cart. I get one of these roll-around carts and fill it with anything I can that is relevant and then some things that may not be even remotely relevant so that you have this big playpen full of stuff that's sitting on the table or it's sitting on the cart: information, devices, data. In this way, brainstorms are like a big open-book exam where you're allowed to bring stuff in.

Brainstorms are not the only arena where potential solutions are drawn from IDEO's organizational memory. Designers routinely ask for technical assistance at the company-wide Monday morning meetings (e.g., "Who knows about sheet metal fasteners?"). They use electronic mail to broadcast questions to the firm, for example, about fasteners, materials, adhesives. A designer explained: "There are often things that people need help on. They put them on e-mail and there's almost always responses. If you get a question and know the answer, you just take the time and answer it and that's part of the job description because you know you're going to get it back." Retrieval also occurs during informal conversations that follow meetings or e-mails, which are facilitated by IDEO's open office plan and (in Palo Alto) encounters that occur as designers walk between the seven IDEO buildings within a three-block radius. Informal conversations often occur between designers who are known to face specific technical challenges (who are expected to ask for help) and designers who are known to have pertinent expertise (who are expected to give help). A designer said:

> I think that people here feel really free about just throwing things out just in casual conversations in the halls. [You ask] "Oh, Lee, I got a problem, maybe you have an answer for me." You stop and help if you've been into brainstormers on some of these things before, and so have some exposure to it, or hear about it at the Monday morning meeting and think about it, or if it's obvious what someone is doing. You stop and throw your ideas out.

Analogic thinking allows designers to take in specific implementations of technological solutions yet retrieve useful solutions for new problems that could not be predicted or that are, in form, distant from the technological solutions in IDEO's memory. The intimate knowledge required to enable such generative metaphors requires problem-solving arenas in which communication of complex problems and solutions are possible. IDEO's brainstorms, other scheduled meetings, e-mails, and informal conversations create such rich communications and allow the retrieval of specific technological solutions that often take far different forms than those in which they entered the organization's memory.

DISCUSSION

We blended network and organizational memory perspectives in a model of technology brokering that explains how one organization develops innovative products. This firm exploits its network position to gain knowledge of existing technological solutions in some industries that may be potentially valuable in others, but are rare or unknown. It acts as a technology broker by introducing these solutions to industries where they are not known, and, in the process, creates new products that are original combinations of existing knowledge from disparate industries. The organization's links to many industries provide its designers with access to a broader range of technological solutions than they would see working in a single industry. Designers acquire and store such solutions in the organization's memory. Then, by making analogies between new design problems and old solutions they have seen before, they retrieve such knowledge to generate new solutions to design problems in other industries.

Because the primary aim of this paper was to blend network and organizational memory perspectives in a model of technology brokering, we have devoted limited attention to explaining how IDEO encourages and supports employees to follow the internal routines that make such brokering possible. Our field study suggests that the organization's role is critical. The structure of the work, norms for collaboration, formal and informal reward systems, and employee selection processes may help explain why IDEO, and perhaps other organizations, have employees with the skill and motivation to carry out these routines.

Organizational Support for Technology Brokering

First, the structure of work at IDEO causes individual designers to face a continual flow of new problems requiring engineering solutions. This flow of new problems provides incentives for them to develop, and opportunities for them to exploit, a wide-ranging knowledge of potential solutions. IDEO's client base ensures that the organization will encounter a range of new problems and new solutions. Within the organization, however, the engineers also do not specialize in any single industry but, instead, often move to new industries after completing a single project in one industry. Engineers also often transfer on and off long-term projects to prevent "burn-out" and allow them to pursue interests in other areas. In a given year, an engineer may design portable computers, vacuum cleaners, medical products, and office furniture. One project manager described this lack of specialization: "As a designer you love variety and, not having to do the same thing for years on end, it keeps you fresh and it makes you more confident that you can use something you learned in this area and move from there." Work is also structured so that teams are formed and disbanded around individual projects and often pull in additional members for brainstorms or short bursts of effort. This movement between teams and projects not only provides designers with a wide range of experiences, it also provides them with exposure to the skills and backgrounds of their colleagues. So the constant flow of new problems, combined with the movement of engineers from team to team and industry to industry, creates opportunities for engineers to develop varied technological backgrounds and to learn about others' distinct knowledge and skills.

These varied backgrounds, and awareness of what others know, enables the engineers within IDEO to act as individual technology brokers by allowing them to draw on their own diverse technical knowledge to help others. Much of this benefit, however, depends on IDEO's strong norms for designers to share their disparate knowledge and help one another. We have proposed that these norms (and the associated values) can be summarized as an "attitude of wisdom" (Sutton and Hargadon, 1996). Building on Meacham's (1990) writing, people who have an attitude of wisdom are cooperative because they are neither too arrogant nor too insecure to ask others for help and because they treat what they know with humility and what others know with respect. Furthermore, wise people realize that they know things that others do not, so they constantly tell others what they know and offer others help and advice.

Newcomers at IDEO are taught the attitude of wisdom at IDEO and old-timers are reminded of it by the everyday interactions of the designers, interactions that are most visible in organizational routines such as brainstorming and Monday morning meetings. Brainstorms foster technology brokering at IDEO by pulling together groups of designers to work on an identified problem. Designers call these meetings to seek the help of other designers at IDEO who are not already involved in that project. In doing so, they demonstrate that they are neither too insecure nor too arrogant to ask for help, that they are treating what they know with humility and what others know with respect. One designer described brainstorms as "useful in getting detailed knowledge about your project out so it stimulates others to suggest solutions or offer leads." Another said, "The main reason I use brainstorms is to generate ideas that I know I wouldn't have on my own." The designers who attend brainstorming sessions do so because they believe they can contribute distinct technical solutions to the problem and because, if they don't help with others' projects, the favor will not be returned. This same sense of sharing was visible in the Monday morning meetings, when designers would announce problems they were working on (e.g., "Who knows about adhesives for sheet metal?") or would present potentially useful or interesting ideas they had recently seen (e.g., handing around an example of a co-molded plastic handle with rubber grip) during "show and tell." These interactions made visible the norms for asking for help, sharing knowledge, and giving help, which taught newcomers and reminded insiders how they were expected to behave at IDEO.

Third, IDEO's formal and informal reward systems provide substantial support for such collaboration. Top managers determine designers' pay and responsibility, and while they place weight on the number of hours billed, compensation decisions are based largely on informal reputation among fellow designers and formal peer reviews. A top manager described IDEO as a "peer-oriented meritocracy," so pay and status are closely related. A designer emphasized, "the only way to enhance your status in the organization is by earning the respect of your peers." Designers do earn respect from their peers through individual efforts that produced good designs, but a designer's reputation is based at least as much on using his or her skill to help others. A designer explained:

> People realize that the way to be respected and to get ahead is to be out there. It doesn't work just to be a grind on your project. I mean, you can do a great job on your project and meet all your goals, but I think the reward structure is set up in a way that if you don't participate in other stuff, that it's probably a little bit of a demerit. People don't know you as well so your capabilities aren't as well understood, you're not as likely to be invited on projects, you're not going to be in demand. So there's a benefit for spreading your knowledge and your skills around because you get to be seen by more people and so you become more desirable.

A designer's reputation among his or her peers is also enhanced by asking for help. Following the attitude of wisdom, people who don't ask for help are thought to be either too insecure or too arrogant, to lack humility about what they know and respect for what others at IDEO know. One engineer compared his experiences at IDEO to other engineering organizations: ''Where I worked before, you just didn't ask for help. It was a sign of weakness. . . .[At IDEO] we don't have time to screw around. At the first hint I don't know something, I'll ask 'Does anyone know about this?' The whole thing here is you've got to leverage as much as possible. You ask for help. You are expected to ask for help here.'' There is especially low tolerance at IDEO for engineers who don't ask for help and then produce poor designs. One designer asserted that making mistakes was viewed as an expected and inevitable part of the design process. Failed or weak design efforts that represented the combined best efforts of a number of IDEO engineers were viewed as understandable. In contrast, designers who made mistakes but had not asked for help were not easily forgiven. Other designers sometimes reprimanded them for failing to follow IDEO's methodology, spread negative gossip about them, and, if they repeatedly failed to ask for help, shunned them by, for example, not inviting them to attend brainstorms or to work on interesting projects.

Fourth, as with performance evaluations, employee selection is done by (future) peers who look for new designers with the right technical knowledge and skill (including backgrounds that bring new design solutions into IDEO) and an inclination to follow IDEO's work practices and norms. A person is not hired unless at least ten designers express strong support for offering him or her a job. Furthermore, approximately 70 percent of IDEO's engineers are graduates of Stanford University's Design Division of the Mechanical Engineering Department. IDEO's CEO, David Kelley, is a tenured professor in the department and, along with at least ten other IDEO designers, teaches product design in this program. A senior designer and long-time lecturer described IDEO's relationship with Stanford: ''I have twenty-five of my students here now. And Kelley, I'm sure, can count more like forty or fifty of the whole seventy. So we use, or have, a nice relationship with Stanford.'' David Kelley and many of IDEO's first employees graduated from this program, so there is much overlap between IDEO's and Stanford's design philosophy. As one designer and teacher put it, ''We're not only following the philosophy of the Stanford product design program, we're setting the philosophy. It's not clear who's driving who now." As a result, IDEO engineers (and others) who teach these design courses socialize students in IDEO's design process and core norms. These IDEO engineers are also able to select newcomers from a pool of students whom they have observed working on design projects. Promising students often perform summer internships at IDEO. A senior designer said, "It's a great way to interview people. We just see these superstars coming through and they see us and they want to work here and we love to have them so we just grab them every year." In addition, the remaining 30 percent or so of IDEO engineers who did not attend the Stanford program usually first worked with IDEO engineers as clients or contract workers, so they learned about IDEO's work practices and core norms and were screened carefully by insiders before being offered jobs. The result is that IDEO's selection process not only screens potential new employees for pertinent technical skills and willingness to seek and offer help in the design process, it may also serve to instill such knowledge and beliefs in designers before they are hired.

These preliminary data from IDEO provide hints about means that other organizations may use to support and encourage employees to act in ways that support internal technology brokering routines, so as to establish and exploit individual ties to distinctive knowledge domains. By structuring work so that employees are exposed to a wide range of industries, individual employees become well versed in diverse, and perhaps otherwise disconnected, domains and the technologies within each. By constantly forming and disbanding teams, employees are exposed to the diverse knowledge held by their coworkers and learn who has what kinds of expertise within their organization. By developing and reinforcing strong norms for exchanging information and for asking for and giving help, employees will feel comfortable asking for help, will know the right people to ask for help, and those who are asked will feel compelled to help. By providing rewards for sharing information and helping others that are at least as great as the rewards for individual accomplishments, employees will cooperate rather than compete, or perhaps compete with one another over who shares the greatest amount of pertinent information and who is most helpful on others' projects. Finally, by screening employees for cultural fit as well as technical knowledge and skill, and by relying largely on what potential employees have shown they will do instead of what they say they can do, an organization is more likely to be composed of people who act, individually, as technology brokers and who help their coworkers do such brokering.

Directions for Future Research

Our effort to blend network and memory perspectives suggests that network theory might be developed further by devoting more attention to the transformation and combination of ideas and resources as they flow through network actors. The transformation and combination described in this paper occurs predominantly through individual actions within, and not between, such actors. Network theory describes the fragmented structure of knowledge across different domains and explains the value of people and organizations positioned as brokers in structural holes. But this perspective treats network actors largely as conduits that pass along unchanged ideas and resources to others. Little attention is devoted to if, how, or why those ideas and resources are transformed and combined into new solutions for other actors and subgroups.

IDEO, like Edison's laboratory, does more than just transfer technological information from groups where it is plentiful to groups where it is dear. IDEO acquires such information, stores it, changes it, and retrieves it to create new combinations of old things. Through this process, brokers create new value (and new knowledge) by adapting and recombining existing technological solutions in creating the specific forms of new products and processes that meet the needs of different markets. Network theory may be enhanced by future research that considers how brokers who span structural holes change the ideas and resources that they transfer and, additionally, how brokers' ability to add value to ideas and resources helps them maintain and further exploit their network position.

The purpose of an inductive study like the one reported here is to guide and inspire new ideas, not to validate existing ideas. The extent to which the local explanation of innovation summarized in figure 1 develops into a more general theory of technology brokering depends on how well it, or its descendants, explains innovation in other settings. One of the first questions for future work on technology brokering is whether or not this local model resembles innovation processes in other settings or is idiosyncratic to the firm that we studied. The extent to which our model generalizes to other organizations can only be determined by hypothesis-testing research in large, representative samples of other organizations involved in creative problem solving. A variety of existing cases suggest, however, that the process we observed at IDEO is much like that used in other organizations doing creative work.

Management consulting firms like McKinsey & Co. and Andersen Consulting profit by bringing to client organizations management techniques that clients were often not previously aware of but that have potential value to solve their current problems. For McKinsey, the result is reported to be a set of clients whose "demand for organizational knowledge and experience cuts across nearly every important client relationship regardless of industry" (Katzenbach and Smith, 1993: 98). Taking advantage of this position between clients and the knowledge these clients seek requires routines to acquire, store, and retrieve such knowledge in forms that their clients can use. To do so, McKinsey uses formal and informal mechanisms to store and retrieve potentially valuable knowledge. One example is their "Rapid Response Team," established to "respond to all requests for best current thinking and practice by providing access to both documents and experienced consultants" from across the company (Katzenbach and Smith, 1993: 98). Arthur Andersen similarly benefits from its ability to broker new solutions based on past experiences. The firm's promotional materials promise to "quickly produce innovative solutions" by drawing on a knowledge base that "abounds with breakthrough quantitative tools along with qualitative best practices compiled from client experiences and exhaustive research,'' and they promise to do so by using the formalized routines captured in their Global Best Practices approach (*Business Week,* 1996). As a result, these management consultants provide their clients with new solutions that are combinations of (what they believe to be) the best management techniques they have seen elsewhere.

Technology brokering may not be limited to consultants. The 3M Corporation is a large manufacturing firm that often finds new uses for existing technologies by adapting and introducing those technologies in new markets. The surface preparation technology known as ''microreplication'' that 3M originally developed for overhead projectors in 1964 has diffused and evolved to provide 3M with innovative products in electronics (magneto-optics), adhesives (smart adhesives), abrasives (structured surface abrasives), reflective materials (street signs and lane markers), illumination (light poles), film (liquid crystal display film), and lenses (low-profile overhead projectors) (Stewart, 1996). Our local model of technology brokering may offer insights into how organizations like McKinsey, Arthur Andersen, and 3M position themselves within a network of imperfectly shared technological knowledge and how they acquire, store, and retrieve past technologies for implementation in new designs for other industries.

Future research might also focus on specifying the environments in which technology brokering is likely to occur. Our perspective suggests that the primary feature of such environments will be a fragmentation in knowledge and communication between technological domains. When ideas exist in one domain that are potentially valuable in others, individuals and organizations can create innovative new concepts by acquiring, storing, and retrieving these ideas in new combinations and by transferring these combinations to new audiences. Technology brokering appears especially likely to occur when new technologies are developed that have potential value in a wide range of industries but such knowledge is not yet widely diffused. Examples include electromagnetic power at the turn of the century and information technologies in recent decades.

The general applicability of electric power meant that inventors like Edison could profit by finding problems in a wide range of industries that electric power could solve. In a similar, though less grand process, IDEO adapts information technologies for use in a range of industries that had previously lacked such knowledge. The historian Hughes (1989), in language reminiscent of March and Olsen's (1976) garbage can model of decision making, described the creative process used by independent inventors at the turn of the century as solutions in search of problems. The presence of technologies with potential value to a broad range of industries allowed organizations with knowledge of these existing ''solutions'' to create new products routinely by crossing industry boundaries in search of new problems. Elmer Sperry, a contemporary of Edison, whose firm pioneered the use of electric motors in gyrostabilizers and gyrocompasses, stated his rationale behind this strategy: ''If I spend a lifetime on a dynamo [i.e., electric motor] I can probably make my little contribution toward increasing the efficiency of that machine six or seven percent. Now then, there are a whole lot of [industries] that need electricity, about four or five hundred percent, let me tackle one of those'' (Hughes, 1989: 54). Theory about technology brokering might be advanced by considering how, given the nature of the technologies involved and the distribution of knowledge about them, environments facilitate or hamper innovation through brokering.

Our evidence from IDEO also suggests that internal routines are essential to organizations that exploit attachments to disparate industries. Organizations that face many different problems benefit from routines for acquiring, storing, and retrieving a broad range of technological knowledge when that knowledge will be useful in solving future problems. IDEO has clear ties to a wide range of industries, but other forms of organizations may hold similar network positions without sharing the same organizational forms. There may be alternative ways of organizing for technology brokering that reflect different environments and different strategies and result in different sets of internal routines. For instance, IDEO and other consulting firms continually explore the environment for new solutions while solving the specific problems of clients in a range of industries. Others, like Edison and Sperry, may innovate by specializing in a single, emerging technology and exploring the environment for possible applications of that one solution. Still other organizations may gain access to a range of industries through multiple divisions and share discoveries (and failures) in one industry that may have potential value in another. Large, multidivisional corporations, for example, have internalized access to the technologies and market needs of different industries. A division operating in one industry may broker potentially valuable technologies to other industries by sharing knowledge between divisions. Mueller (1975: 326) described the discovery by DuPont researchers of Duco lacquer, which reduced the drying time of automotive paint from days to hours. Seeking an improved photographic film, these researchers recognized in a failed experiment the potential for a new product in a wholly different industry. By adding pigments to a congealed and useless solution for photographic film, they created a vastly improved automotive lacquer. DuPont's access to such a broad range of industries and its internal routines for sharing problems and solutions turned a failed photographic film experiment into a highly successful automotive product. Organizations that have developed routines for technology brokering may be better able to take advantage of such serendipitous discoveries. Theory on technology brokering might be enhanced by considering the routines that such firms use to match potentially valuable technologies found in some parts of the organization with needs in other parts.

CONCLUSION

Our model of technology brokering suggests that innovation can and should be studied by considering both the social structure of technological knowledge and the internal routines of organizations able to exploit that structure. Innovation through brokering may generalize beyond technological innovations within the product development process. Scientists, artists, management consultants, and others involved in creative problem-solving efforts often build innovative new ideas by recombining existing ideas. It is an old notion that innovations are built from existing works, but the image often remains of the lone genius inventing ideas from scratch. Technology brokering offers a perspective on innovation and innovators that recognizes the value not of invention but of inventive combination.

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