Computer Support for Technological Innovation

Wendy E. Mackay
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1. Introduction

The goal of this paper is to develop a general research framework for understanding communication within small groups and how it supports technological innovation. The framework itself is very broad and draws upon a number of disciplines, primarily management of technological innovation, coordination theory, and adult learning. I hope to develop a dissertation project within this context that will serve as an initial test of both the theory and the research methodologies and provide directions for future research.

Successful technological innovation must include not only the generation of new ideas, but also the development of ideas into useful results. Unfortunately, we do not fully understand this process. We need to learn what characterizes successful innovation efforts and how best to manage them.

Technological innovation has many dimensions and can be studied at many levels, ranging from macroeconomic views of multi-national corporations to the psychology of a single individual's creation of a new idea. This work will focus on the communication aspects of technological innovation and the scope will be limited to collaborative work accomplished by small, interdisciplinary groups. Computers will play a number of roles and will be used to both alter and study the process of technological innovation. My goal is to develop:

1. a theory of communication for supporting innovation.
2. prototyping tools to support such communication.
3. a research methodology for studying innovation in the field.

2. Theory

What is it that makes a group innovative? Are there factors that increase the probability that the right problems will be defined, that creative solutions will be found, or that projects will be successfully implemented? Allen (1977) showed that technical communication within a laboratory has a major effect on successful innovation. Yet not all sources of information or channels of communication are equally useful. For example, Allen found that contact with people is far more useful than reference to written material, both in definition of problems and in generation of solutions. He also found that contacts with people outside the organization was the most common, although not the most effective source of ideas. Is there a theory that specifies why this might occur and suggest ways to increase the effectiveness of both written and interpersonal communication? In other words, can we specify how to provide the right information to the right person at the right time?

In order to understand why different information sources and communication channels work better than others, it is important to understand both the optimal ways of providing access to information as well as the associated costs. A useful model will not only predict which communication channels are most effective, but will also suggest how to change the cost/benefit ratios to improve the chances for successful innovation.

Throughout the development process, individuals and groups are faced with different kinds of problems and thus different kinds of information requirements. Even at a specific point in time, an individual may be faced with a variety of information needs. Mackay (1987) developed a matrix of information presentation

styles based on two questions. First, is the individual capable of clearly identifying the necessary information or is help from some outside source required? Second, is the organization of the information dependent on the individual's specific problem? Answers to these two questions form the basis for four forms of information: reference material, instruction, simulation, and tutoring. If the model is correct, it should be possible to predict the optimal presentation style for any particular situation. Note that people are capable of providing all forms of information, whereas written material is more limited. People can answer specific questions or brainstorm new ideas. They can tailor explanations to specific problems and take into account subtle organizational issues. In a sense, a partnership is formed, as both people try to identify the form and the content of the information.

How can we explain Allen's finding that technical journals and company reports are not very useful? Part of the answer may be that the information simply does not exist in those forms, but this is often not the case. The problem is that the cost of finding the material is too high -- asking someone is much easier. There are, however, different costs associated with asking different people, and the quality and relevance of the information varies. It takes more time to sift through written material than to simply ask someone, especially someone you're talking to anyway.

Von Hippel (1987) has identified another important information issue: the economics of information exchange. Rival firms have economic incentives to trade rather than protect certain kinds of information. Over time, organizations develop mutually beneficial information trading patterns.

Individuals may find themselves facing similar economic issues and react in similar ways. Blau (1963) views consulting within an organization as an economic transaction in which both information seekers and consultants have costs and gains. The former must trade the risk of losing prestige against the potential gain of obtaining needed information. Similarly, the latter may gain prestige, but lose valuable time from work. As in Von Hippel's example at the level of the firm, transaction costs must be evaluated over time. Obtaining consulting incurs an obligation that will either be repaid or will result in a refusal to provide further information.

This economic model may explain Allen's finding that external consultants are used more frequently than internal consultants, even though the information obtained is less valuable. "For many reasons the outsider is often more approachable and more willing to give of his time than is the organizational colleague." Also, the potential for lost prestige is lower with an external consultant. Gatekeepers play a special role, in that they are able to successfully communicate with and contribute to internal and external organizations. They act as information brokers, benefiting from the exchange of information.

Organizations judge how much written information to purchase or produce based on perceived benefit for an expected number of users. Individuals also weigh the short and long costs and benefits, in terms of access time, obligations incurred and position within the organization.

Having established that increased communication among groups increases R&D effectiveness, and also that information exchange has economic costs that can be modified, the next question is whether it is possible to systematically modify the kinds of communication and the corresponding costs and benefits to increase R&D effectiveness in predictable ways. ==== What's missing here is the computer. We've established that people are more effective than written material. We've developed a model that may explain why. Now we need to prototype new forms of communication that provide the right information at the right time, with the optimal ratio of cost to benefit.

2.1. Collaborative Work

Sometimes a single entrepeneur can be both the source of an invention and the one responsible for bringing it to market. More often, though, groups of people are necessary, both as stimuli to the creation of the idea and to support the development of an idea into a successful product. Unfortunately, it is difficult to tell what kinds of information are needed. Often too much information is available, making it difficult to find what's essential. Also, relevant information may exist, but its availablity unknown. Finally, information may exist in different formats or from different points of view that are not useful. How can we create a theoretical model of information that provides a way of identifying when and how to present information.

Believe that people need to have access to other people and other information at the right time in order to innovate and to sell innovations. Communication networks are an essential aspect of innovation.

Must address it both organizationally, managerially, etc. Build in interdependencies, balance collaborative with solitary work. Balance competitive with cooperative work. Focus on support for individual achievement and support by team.

3. Software Tools

The computer will play many roles in this research, serving as a source of information, a medium for information exchange, and a device for recording and analyzing information about human communication and innovation processes.

3.1. Iterative Design Model

3.2. Video Prototyping

3.3. Permanent Prototyping

Based on this framework, we can identify tools that support the important kinds of communication and increase our ability to successfully manage it.

Written material has many limitations that increase both its production and access cost and lower the benefits. People, on the other hand, are far more flexible. They can accommodate different information needs in a way that paper cannot. However, the costs of talking to people may be high, access may be limited, and benefits may vary according to

Existing written may well have the required information, perhaps even in the optimal form, but the costs of obtaining it are high. Prior to the computer, information could only be pre-organized into written form.

4. Research Methodology

Different research areas can contribute to such a theory, ranging from psychology, organizational behavior, collaborative work, etc.

The theoretical model must identify how and when people need information, and identify how to provide information, even when people can't ask for it directly or don't know they need it. A cost/benefit analysis may provide some insight as to why certain sources and media are more useful than others. Can we lower the cost or increase the benefits...

Research in this field has a number of conflicting problems.

To develop a theory of technological innovation in small groups and develop a research methodology for discovering and testing the relevant factors.

None of the standard methodologies seem sufficient.

Four different methodologies:

1. Psychology: theories tested with controlled laboratory experiments
2. Economics: mathematical models tested with historical data
3. Computer science: computer systems that illustrate ideas
4. Social Sciences: observation in the field to derive theories

4.1. Collaborative Work

Problem: people don't always know they need info or what kind. Can't always ask for it.

Solutions: organizational. Design a group with built in interdependencies that tie people together with necessary, complementary skills and knowledge. Not just within organization -- support for knowhow trading.

Information database -- understand that user is at center of info needs. Create different ways of getting to it.

Want essential info -- not too much, not too little. Lens and semi-structured messages.

Multiple views and different levels of abstraction -- Zachman. Abelson. help people communicate. Identify communications breakdowns -- build in data collection into organizational structure to facilite on-going communication.

5. Communication Issues

Allen (1977) showed that technical communication within a laboratory is critical for successful innovation. Both his research methodology and a number of his findings are relevant to this work. The research methodology

First, He identified two important activities, defining problems and suggesting solutions, in which successful results were obtained significantly more often from and found that other people, rather than the written literature.

Allen's work is important in that he has measures of performance. Simply identifying percentages of types of communication is not sufficient. The picture changes dramatically when performance criteria are included, since higher performing groups exhibit different communication patterns than lower performing groups.

(Note chicken and egg problem -- are the communication patterns the result, the cause or both othe these differences?)

"A greater number of ideas for solution were suggested by sources outside the laboratory than by all other sources combined". Why? Psychological cost associated with using outside sources is lower than inside. BUT, lower performing groups do this more. WHy? Because outsiders are less likely to understand the organizational culture and the ways in which problems can be solved in the organizational context.

Technological gatekeeper -- way to keep in touch with outside, but everything filtered through a high performing person who understands what's going on outside and the internal cultural boundaries.

Expect size of communication network to grow, since cost of maintaining weak ties is lower. Can help gatekeeper keep in touch better with outside and can help others keep in touch with gatekeeper at lower cost to both parties.

This is confirmed by the "Knowhow Trading" observed by Von Hippel (1987), in which ....

By examining pairs of engineering groups as they solved identical problems (in the field), Allen et al were able to identify factors strongly correlated with the more successful groups.

General One important finding was all engineers were more likely to use other people rather than written literature for both defining problems and generating successful ideas.

Why? What is to be done? As Allen states:

> Certainly not much time and money should be invested in developing systems to improve the engineer's ease of access to information he cannot and will not use anyway. Instead of wasting energies on such a fruitless undertaking, we should attempt to close the gape between producers and consumers. The principal reason for the reluctance of engineers to use their professional society journals is very simple: they cannot understand the material published in them. Given the aim of bringing engineers into greater contact with tehir professional literature, there are two obvious approaches. The first approach, directed toward the engineer himslef, is to enhance his mathematical sophistication so that he can understand the literature. The second approach is to bring the literature to the level that the engineer can use.

He goes on to suggest that a larger number of specialized journals, each with very intensive editorial attention, be created.

The technical societies have "failed to address the central questio of the role of written communication in technology and the role of the engineering society in society at large."

The first goal of engineering publication is to inform, not to stake out claims. (Can the neuro project do

both?)

One can infer from this that despite his technical sophistication, the engineer finds the professional journals in his own field unsuited to his needs. He is better able to obtain all of the needed information in his own field through personal contact.

"Perhaps the combination of articles from Scientific American to provide general concepts, followed by explorations in the more quantitative papers of the typical professional journal, is what is needed to best expand one's skill base in new directions."

Engineers don't look in libraries.

An important finding was that successful ideas are more likely to come from other people rather than via the technical literature (approximately 70% as opposed to 20%). One possible explanation is that people are far more flexible than printed words.

Another finding was that technical literature was most useful in the initial phase of the project, perhaps providing the information necessary to understand the issues in the problem. Also, Allen and Marquis (19xx) found that generation of new ideas -- early phases of problem-solving better to consider a large number of Why was technical information less useful later? It may be that it is because of the limited way in which it can be accessed... not useful enough to answer specific questions.

Can we change the parameters and see the effects on innovation? Can we lower the costs or increase the benefits of information exchange and provide a corresponding increase in the level of successful technological innovation?

No accident that people are more useful sources of information than paper -- because paper is predetermined, predefined. Because technical literature is organized as reference or reports re: something -- lots of answers, but you have to provide the right question and link the solution to it. People are much better at synthesizing information, and responding to questions. (Literature doesn't answer questions directly.) Note - textbooks are also a big source -- better at answering direct questions. Have to be the kind that

Individuals within a group use a variety of information media, including journals, etc. Higher performing individuals and groups,

I would like to identify the circumstances under which certain kinds of communication are most effective, explore the kinds of communication that are critical,

Distinguish between information content and medium of expression.

People can provide very sophisticated information filtering services for their colleagues, synthesizing information from technical publications, other people and their own experience and providing succint explanations for their colleagues. People communicate in many ways, sometimes face-to-face, sometimes by phone, sometimes by paper. Each medium has advantages.

Computers not only provide an additional medium with a range of characteristics, but also new ways to access information. Electronic mail and on-line conferencing systems are examples of the former, real-

time simulations and expert systems are examples of the latter. It is important to avoid thinking of computers as "unitary" phenomena, like telephones or cars. They are extremely flexible and serve many functions, from performing rapid calculations of formuli, to simulating real-world phenomena, to helping people write papers. Recently, as networks of computers become more prevalent, attention has turned to the problems of supporting the work of groups of people, not just individuals.

Why computers? Not just another telephone or automobile.

The field of Collaborative Work is ... just beginning to explore how computers can help groups of people work together. groups of people collaborate.

to absorb and communication information from people and other sources. If we can provide the right information to the right people at the right time, can we increase the level of successful technological innovation? If so, what are the organizational structures and the communication tools necessary to ensure ongoing innovation?

Finding the right research methodology is difficult, and one of the issues I hope to address. The methodology should provide a way to rigorously test theories under real-world conditions, using non-obstrusive measures. Ideally, the methods of collecting information should also be used by the group to monitor and improve their own information management and organizational structure.

In order for the computer to be helpful, we have to first understand what kinds of communication are necessary to enhance technological innovation. Allen sociogram. Given this information, we can then examine what kinds of support the computer can provide that will increase the effectiveness of this kind of communication. Also, we have to understand the organizational implications of trading information. Simply making it available is not sufficient -- must understand how to get it to people when they are optimally ready to absorb it. Also, recognize the political and power issues associated with sharing information -- knowhow trading.

The research must address both organizational issues as well as technical support issues. Managing creative individuals requires different management styles, reward structures, and values. We know from Allen, et al that managing scientists differs from managing engineers -- does this affect the way we support their innovation? Is it possible to use telecommunications and computer software to enhance relevant kinds of communication. Also, von Hippel points out the economic bases for introduction of new ideas -- those who benefit are most likely to innovate. How to provide the appropriate resources to the right people?

Several assumptions based on observation. First, learning continues long after school ends. Much innovation is based on learning information, even if already known by others, and applying it to a new problem. Assume that support for on-going education, support of learning-to-learn, will help innovation in the long run. Also, work and learning are mixed up together. Don't think of it as a separate function to be addressed later -- much more effective if learning occurs in the context of the work being done. Also, communication networks are critical for making sure that good ideas move throughout the organization. Computers won't be the panacea and are clearly inappropriate for certain kinds of learning and communication. BUT, if they can facilitate certain kinds of essential communication/learning, but lowering the cost or increasing the benefit or both, then we should expect to see an increased level of successful innovation. Also, once it's on-line, we have better methods of recording and logging communication and

learning patterns, even if primarily "off-line" in nature. Can identify which aspects of which tools work, can prototype things quickly and test the prototype before investing in the development of the real system.

Management of innovative people must be different -- must deal with the problems of information overload and inadequate access to information. Central tenet.

6. What I want to do

Computer support for developing information tools. This is the video prototyping idea -- create a method of prototyping things like ECS and Info DB in the field, record things unobtrusively. When working properly, can become part of the ongoing information structure of the organization. Permits field work with controls and detailed data.

Computer support for studying the use of information tools. Experiments such as the editor tutor experiment. Study how people communicate, when/how/why necessary as related to innovation (measured in terms of performance -- short and longterm?). How do info tools affect this? Improve? Theoretical understanding of why?

I will draw upon what, at first, appear to be two conflicting research models. The first is derived from my background in Experimental Psychology, in which rigorous, carefully-controlled experiments comprise the basic research values. The danger in this methodology is the possible lack of external validity. Phenomena that can be isolated and studied in the laboratory may not be relevant in an actual business environment. On the other hand, to the extent that these research techniques can be applied to the business world, the findings will be much stronger.

The second research model derives from my experience as a manager of both production and research groups. Here, the goal was to produce innovative products, methods and ideas that met specific business needs. The danger here is the possible lack of internal validity and reliability -- drawing conclusions that cannot be generalized.

I believe that a research program that successfully combines these two research models will be more effective than either individually. I will attempt to demonstrate how the organization of a research group can provide built-in controls. I will also describe several technical advances that will permit new, unobtrusive methods of collecting relevant data. Finally, I will describe several theoretical models that provide hypotheses that can be tested within this framework.

6.1. Information Environment

Imagine a work envirnonment in which people had access to lots of information with better filters, and that they ...

6.2. Management Structure

Built in controls, like in R&D group.

6.3. Protection of Innovations

Protection of innovations. Must deal with the problem that innovations are easily copied by others, so the innovator bears the higher cost.

Can deal with by continuing to be ahead (GI Joe doll model -- able to produce in volume -- being first.) If the innovation process is difficult to immitate, because it takes advantage of different values of people and management and computer structures that are different than others can have. Note example with smart house -- what makes it work is the level to which people cooperate across industries.

Clever use of standards...

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