COMMUNICATION PATTERNS OF ENGINEERS

CAROL TENOPIR
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IEEE Education Society, *Sponsor*

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PREFACE

In the fall of 2000 the Engineering Information Foundation (EIF) Board of Directors asked Donald W. King to advise them on possible future research directions. In a presentation to the Board, Mr. King recommended a four-phase approach to a research agenda regarding the communication of engineers, starting with a review of recent literature to identify where benchmark data exist, where there are gaps in research, and where future research would be beneficial to the engineering communities. As a result of this recommendation, the Board awarded a research grant to Carol Tenopir and Donald W. King to conduct a literature review and to present recommendations for future research directions. The report to EIF was the genesis of this book. The report focused on the literature from 1994 to the present pertaining to how engineers communicate. This book expands that focus to include literature from the 1960s to the present. The emphasis, however, remains on how engineers communicate, whether communication patterns have changed, and what might be done to improve communication of engineers.

This book broadly defines communication as encompassing information inputs such as seeking, locating, obtaining, and using information on the one hand and information outputs such as writing and oral communications. A particular emphasis is on how communication can be improved through education. We analyzed the literature that touches on these topics, particularly the research literature with engineers as the subject, either wholly or in part. We also extracted survey responses from engineers who were observed nearly every year from 1977 to 2003. These data provided useful insights into engineers' communication patterns and useful comparisons with science and other fields.

This project has been a group effort (not unlike the trend in engineering toward collaborative works). Project leaders Carol Tenopir and Donald King were ably assisted in all aspects by Rhyn Davies, Christine L. Ferguson, Edward Gray, and Scott Rice, graduate students at the University of Tennessee, School of Information Sciences. In addition, graduate students Katie Darraj, Keri-Lynn Paulson, Emily Urban, and Mercy Ebuen assisted with occasional specific tasks. At the University of Pittsburgh, School of Information Sciences, Sarah Aerni, Richard Daddieco, Matt Herbison, and Gina Cecchetti also made helpful contributions.

Without the initial funding and encouragement by the Engineering Information Foundation, this project would not have been possible. We would like to extend special thanks to the EIF Board, including; Melvin Day; Thomas R. Buckman, President; Anne M. Buck, Vice-President; Hans Rütimann, Secretary; John J. Regazzi, Director; Julie A. Shimar, Director; and Ruth A. Miller, Executive Associate. Their comments, corrections, and encouragement were essential to this book. The authors also wish to partially dedicate this book to the memory of Anne M. Buck, a dedicated and caring engineering librarian.

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Knoxville, Tennessee
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August 2003

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INTRODUCTION

1.1 FOCUS OF THE BOOK

This book is a review and analysis of the literature and presentation of data from a series of surveys that attempts to provide insights into how engineers communicate. Much of the focus of the book is on the professional aspects of engineers' work, the information resources used to perform their work, and information output from their work that is communicated to others. Many of our studies and those of others dealt with traditional interpersonal and written communication channels. Together, these studies provide abundant evidence of the many factors that motivate engineers to use various communication channels. However, it seems clear that new technologies, such as the World Wide Web and electronic publishing, are having a profound effect on engineering communication patterns. We believe that knowledge and understanding of engineers' motives, incentives, and reasons for communicating in the past will help frame future communication practices.

During the late 1980s and early 1990s, the Internet, and specifically the World Wide Web, became popular, making electronic and digitally based products (i.e., electronic journals) not only possible, but economically practical. By the late 1990s, electronic products became widely available and accepted by authors

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and readers. The Internet has dramatically increased the potential for both informal and formal communication. People have the option of easy and immediate contact with friends and colleagues all over the world, there has been an evolution of intensive groups of engineers on the Internet with interests in materials, nanotech, electronics, and so on. They can choose which format of many best suits their communication and information needs and requirements. Libraries also now have the option of choosing between print or electronic formats. Libraries and information centers exist to provide information services to their users, so it is important to find out which formats users prefer and how potential benefits offered by electronic resources will facilitate the research and development process and help (or hinder) engineers to do their work. Consequently, interest has increased regarding studies of and publications on scholarly communication and information exchange processes and systems since 1994. Many of these are directly applicable to engineers.

This book synthesizes the historical context surrounding early studies on the communication practices of engineers and scientists; looks at various aspects of communication through scientific and technical information (STI); examines the literature that distinguishes the information needs and uses of engineers from those of scientists; and offers a review of significant studies and projects that explore the communication practices of engineers.

The 1950s witnessed several excellent studies of how engineers and scientists communicate; however, research and surveys on the relationship between scientific activity and STI research took off in the 1960s, largely due to funding from the U.S. federal government and governments in Europe. The 1970s and 1980s saw a continuation of these studies, although this research slowed down by the early 1990s. Most of these studies defined communication broadly to include the creation of knowledge and its preparation for dissemination, the numerous channels by which it could be transmitted, and the assimilation and use of information the engineers received. Various meanings to the terms "information needs," "information seeking," and "information use" are found in the literature. For example, to some communication researchers "information needs" refer to the sources of information used, while for other researchers, "information needs" apply to the information content needed by engineers. Still others define "information needs" as the reasons for needing information.

Five types of models were used to examine STI communication in communication research since 1970. These models either:

1. Focus on communication during research and development projects and tasks; or
2. Follow the flow of information between individual engineers; or
3. Track information through its life-cycle; or
4. Examine the amount of information activity and use involved in specific work activities or by specific participants; or
5. Measure the amount and characteristics of information flow between various functions and participants.

It has been well documented over several decades that engineers spend much of their time communicating. This is often done to enhance their professional performance, as there is ample evidence of a correlation between engineers' communication and their work performance. However, the importance given to different types of information (e.g., literature versus interpersonal exchange) being communicated varies among studies. Furthermore, choices from among information sources are often dictated by factors, such as ease of use or cost considerations.

Many studies found that personal and interpersonal information sources are used initially by engineers and that internally published technical reports are favored over externally published documents. For this reason, uses of journal articles, books, and other sources of externally published material were given less emphasis by communication researchers. Later research began to focus on the importance of journal articles and discovered that engineers in universities read scholarly articles a great deal and engineers elsewhere read them less frequently, but value them nevertheless. Research and engineering education also began to focus on the importance of writing, presentation, and other communication skills.

The research on secondary sources of STI during this period was as extensive as that on primary sources. Most of the studies on secondary sources focused on automated bibliographic searching, with little attention on printed indexes or numeric databases. Studies from the 1960s dealt with the quality of output from information retrieval systems. Studies in the 1970s and 1980s of automated bibliographic databases tended to address evaluation or research involving system innovation and on "end-user" searching. Library resources and librarians were shown in the literature to be "under-used" by engineers in the completion of major projects. Libraries often fill a niche in the communication process, however, by providing for special needs, such as identifying and providing access to older or costly material.

There were many extensive reviews of engineering communication and related literature throughout this period. These include chapters in the *Annual Review of Information Science and Technology* (Menzel, 1966b; Herner and Herner; Paisley, 1968; Allen, 1967, 1969; Lipetz, 1970; Crane, 1971a; Lin and Garvey, 1972; Martyn, 1974; Crawford, 1978; Dervin and Nilan, 1986; Hewins, 1990; King and Tenopir, 2000); several books (Pinelli, Barclay, Kennedy, and Bishop, 1997a,b; Griffith, 1980; Kent, 1989; Nelson and Pollock, 1970; Mikhailov, Chernyi, and Giliarevskii, 1984; Williams and Gibson, 1990; Hills, 1980; Katz, 1988; Tenopir and King, 2000a), reports such as those produced by Pinelli and colleagues and King with Casto and Jones; and PhD dissertations such as Raitt.

Studies concerning STI communication often do not make the distinction between scientists and engineers. Authors who discussed the variations between the two groups before 1994 include Gould and Pearce (1991), Blade, Rosenbloom, and Wolek (1967), Allen (1988), and Pinelli (1991). Engineers were found to rely more on informal and interpersonal information sources than of published literature (Rosenbloom and Wolek 1967; Allen 1988) and they also read fewer journal articles and use the library less than scientists (Griffiths, et al.).

Several sustained and exemplary STI communication research projects were performed from the 1960s through the current time. All of these studies have relied heavily upon data collected from statistical surveys of engineers. The first of these studies, by William Garvey and colleagues at The Johns Hopkins University, began in the early 1960s and lasted until the 1970s. Their work had two major foci. First, they were interested in the "flow" of STI through various communication channels such as internal reports, professional meetings, journal articles, and so on. They developed a timeline to show when created information would appear in each of these channels. Second, they examined which sources of information engineers used for completing their work activities.

Thomas Allen and his colleagues at the Massachusetts Institute of Technology performed another series of studies initiated in the mid-1960s which continued into the early 1990s. Their work involved "record analysis" and self-administered questionnaires of engineers, which revealed that there are often individuals in an organization known as "stars" or "gatekeepers" upon whom others heavily rely on as sources for internal and external information. They identified nine basic information channels and determined the extent to which each of these channels are used, the value of these channels, and the factors which lead to their use.

King Research performed statistical descriptions of STI from the 1970s to the 1990s. Under National Science Foundation (NSF) contracts, King Research performed a series of studies to develop statistical indicators of STI. This research provided trends and projections for STI literature, libraries, authorship and information use by scientists and engineers, and STI expenditures in the United States. One finding debunked the myth of an "information explosion." Rather, growth in the literature merely reflected a growth in the number of scientists and engineers, a fact that holds true today. In 1976, they began research on the feasibility of electronic publishing of journal articles and concluded that the short-term future would have a two-tier system of dissemination (print and electronic). Results from the journal studies led to a book (King, McDonald, and Roderer, 1981) in which the entire journal system is described in detail. They then started research in 1981 to explore the use, usefulness, and value of STI and the contribution that STI services make to these outcomes. From the 1980s to the late 1990s, King Research performed numerous proprietary studies in various organizations to determine the communication activities of professionals (including scientists and engineers). Their work found that engineers and scientists spend a majority of their time communicating. They also found that engineers and scientists use a variety of information sources with choices being dictated by economics among other factors (new analyses from these studies and more recent comparative data are included in several chapters in this book). A continuation of these studies is being continued at the University of Tennessee (Tenopir under SLA, EIF, and other sponsorship), Drexel University, and University of Pittsburgh.

From 1977 to 1981, Hedvah Shuchman and colleagues of The

Futures Group conducted surveys of engineers employed at 89 firms. Sponsored by the NSF, these surveys examined the steps used in locating information needed to solve a project or task. The most important steps were personal stores of technical information, informal discussions with colleagues, and discussions with supervisors. They also found a discrepancy between the sources of information used and sources of information produced.

Beginning in the early 1980s and continuing into the 1990s, Thomas Pinelli, John Kennedy, Rebecca Barclay and their colleagues examined the diffusion of knowledge through the aerospace industry. Their work was undertaken as the *NASA/DOD Aerospace Knowledge Diffusion Research Project* and was done in collaboration with the NASA Langley Research Center, the Indiana University Center for Survey Research, and Rensselaer Polytechnic Institute. The project tracked the flow of STI at the individual, organizational, national, and international levels and examined the communication channels in which STI flows and the social system of knowledge diffusion. More information on the NASA/DOD Aerospace Knowledge Diffusion Research Project can be found in Chapter 12, which is dedicated entirely to this extensive research.

The data for this book are derived from many sources. A primary source is from readership surveys performed by King Research and the University of Tennessee School of Information Sciences, totaling results from over 15,000 scientists. Conducted since 1974, these surveys looked primarily at journal readership, although use of library and other information services was also considered. Data also came from the tracking of 715 scientific journals over a 40-year period and numerous cost studies of scientists' activities, library services, publishing, and other processes relevant to the journal system.

1.2 STRUCTURE OF THE BOOK

In Chapter 2, we describe a few of the many models that depict engineering communication. The principal models presented here attempt to illustrate the complexity of communication processes, which consist of many interpersonal or oral channels (e.g., informal and formal discussions, presentations, lectures, etc.) and written or recorded channels (e.g., letters and e-mail, electronic engineering handbooks and manuals, documentation of work, conference proceedings, articles, books, patents, etc.). Multiple channels exist because each serves specific information needs and requirements. Some information passes through a multitude of channels over time and a model is presented describing the “life” of information through these channels. Some channels, such as those found in the literature, involve many important system-like functions and the participants who perform these functions. These relationships and the life cycle of information through the journal channel form the basis for other communication models that are changing with new technologies.

Chapter 3 discusses the interrelationships among the engineering professions and work performed, resources used to perform engineering activities, and the output from those work activities. Information, of course, is an essential input resource to the work process, as well as a tangible output from the work process. We emphasize that receiving and using information requires substantial amounts of engineers’ time, as well as, the use of information seeking tools such as technologies and library resources. The same is true in information outputs such as in preparing presentations and documents.

Chapter 4 deals with the engineering profession and how engineers go about their work. Examples are given for the amount of time engineers (in industry and government) spend in various work activities and the relative importance of information resources used by engineers to perform these activities. We also discuss engineers’ general communication practices and how well they adapt to communication innovations. The fourth chapter also investigates how engineers assimilate new information into the work process, how they revise their work to take advantage of it and what the outcomes are of using the information. New information may also render old information obsolete, or indicate new, previously unimagined possibilities for the use of old information. We also examine how new technology might improve how engineers communicate in the workplace.

In Chapter 5, we first examine information seeking and use by engineers. There are three stages to this process: information seeking, information receiving, and reading/listening. Engineers, having decided that they have a need for information, must attempt to find information that best suits their need. Both of these processes form information seeking. When they have identified some information, in the form of an article or conference proceeding, for example, they must then attempt to acquire the information. There are many possible avenues through which users can acquire information: from asking a colleague, using a library resource, to logging a formal request for document delivery with a reprint service. The third stage, reading/listening, is the incorporation or assimilation stage. There are many levels of incorporation. Sometimes people skim through an article, only reading the principal statements and glancing at the figures; other times people, read very thoroughly; and most times people do a combination of the two at different times. Some of our research and data reveal evidence about the way engineers read relative to scientists in other fields. There has been less research on listening by engineers; however, since so much of the communication by engineers is oral, studies of listening and understanding are of particular relevance to the education and research communities. In this chapter, we also describe the extent to which channels are used and how much time is spent in information seeking and use. Chapter 6 pays particular attention to factors that affect engineers' communication channels, such as geographic or cultural differences among engineers; differences among branches of engineering; nature of the work performed; organizational policies; and personal characteristics such as gender, age, and so on.

Chapter 7 explores the facets of output and communicating information. The two major aspects in this chapter are writing and presentations. This is the communication stage, wherein engineers disseminate the results of their research or engineering output to their colleagues or to the public. We explore trends in how engineers communicate information in writing, verbally, in conferences or presentations, or in formal education settings, such as classrooms. We provide estimates of the amount of communication (e.g., presentations made, proposals written, etc.) and the time spent communicating. Chapter 8 discusses how education and training are changing in order to improve communication skills of engineers.

Because of the importance of engineering journals and the changes due to electronic publishing, Chapter 9 is devoted to the engineering journal channel. In this chapter, we examine the trends in authorship, reading, information seeking patterns, and publishing of engineering scholarly journals. We also present specific readership data: How articles are identified and where they are obtained. In particular, we present survey results for engineers' reading patterns before and after electronic journals became available.

Since electronic publishing is making a profound impact on information seeking and reading patterns, we devote all of Chapter 10 to survey evidence of these changes. This chapter examines current (2000 to 2003) observations of the use, usefulness, and value of journals; where engineers now obtain their articles; how they learn about the articles they read; the format read (print or electronic); issues concerning the age of articles read; and factors that affect choices from among journals read, sources used, and means of identifying articles.

Chapter 11 examines differences in engineers' communication patterns and also differentiates between engineers and scientists and medical professionals. Knowing precisely how expectations and communication styles differ between cultures can inform and potentially improve collaboration between engineers in different regions. It is equally useful to examine how information use patterns vary depending on the gender, age, level of education, or experience of engineers. Work roles assumed by the same individual over time and specialization in different fields of engineering also affect how engineers use information, because the types of goals and the procedures required to meet them differ substantially with different work roles or branches of engineering. Even stronger differences exist between engineering as very practical and applied, and science, which can be more theoretical and experimental. Chapter 12 elaborates on the extensive work performed by Pinelli and colleagues, which was discussed earlier. Finally, Chapter 13 summarizes the findings and provides conclusions about the communication patterns of engineers.

2

COMMUNICATION MODELS

2.1 INTRODUCTION

Innovation never happens in a vacuum; innovation requires communication. Just as work on the cutting edge of engineering and science has become more technical and complex, so too has the process of communicating. In becoming so, communication has unfortunately also become more complex and cumbersome for many of the engineers. Engineering is increasingly collaborative, multidisciplinary, and global, but the goals of engineering projects are becoming progressively more refined and specialized. Generally, the more narrow the discipline and the more specialized the information needs of its practitioners, the more difficult it is to find good information easily. Engineers are rarely taught advanced techniques of information retrieval, however, and are typically not naturally gifted communicators, making it difficult to fill their complex information needs (which can then impair their ability to produce high-quality work).

In the quest to make all stages of research, development, design, and production as efficient and effective as possible, it is important to posses a clear understanding of how engineers determine their information needs, fill them, use the information, and share their own resulting information. By discovering these patterns and systematizing that knowledge, communication can

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be improved and communication at all stages of engineering work can be made more effective. This, in turn, increases the potential for high-quality progress in engineering endeavors. This chapter presents some of the major conceptual communication models and publishing endeavors that laid the groundwork for understanding those processes. The remaining chapters focus more specifically on current issues of how engineers communicate.

2.2 MODELS OF COMMUNICATION SYSTEMS

Many scholars have studied the systems of communication and the processes of information exchange, both in general and in specific subject domains. Several contain conceptual models that portray these complex patterns. The SCATT Report, by R.L. Ackoff, et al. (1976), describes an ideal Scientific Communication and Technology Transfer (SCATT) system that can be scaled to regional, national, or international levels of use. (See Figure 2.1) Ideally, the SCATT system facilitates the movement of scientific and technical information in multiple forms (audio and visual), multiple registers (formal and informal), multiple levels (primary—new information; secondary—about the new information; and tertiary—about the content of other messages), and multiple stages (production, dissemination, acquisition, and use). Each of these forms, registers, levels, and stages is an element of communication and so must be examined both individually and in interactions with the other elements in any useful exploration of the subject.

For example, an engineer develops a new technology, writes the patent application for it, and makes a video demonstrating how it works (stage 1). The patent is awarded and the videos are sent to other engineers around the world (stage 2) where they watch the video (stage 3). The other engineers take this new information (level 1) and talk about it (level 2) with their co-workers around the water cooler (informal register), and may also present it during a project meeting (formal register).

They begin to theorize about what they discussed at the water cooler or in the meeting (level 3) and might test elements of this invention against their own ideas for making it even better (stage 4). As the information moves from the initial pool of new information through each stage of communication, the new ideas that it creates may result in new information that can be fed back into the original pool of information, thus starting the cycle again. Many communication systems rely on a selection of these elements, but a system that integrates them all could be used to provide scientists and engineers with whatever information they need, whenever they need it, and in whatever form would be most useful to them.

Garvey and colleagues at The Johns Hopkins University (Garvey and Griffith, 1972) and others have described the variety of channels by which scientific and technical information content is communicated. Some are oral in nature (e.g., oral reports, informal discussions, meetings and conferences), while other channels involve information recorded in documents (e.g., informal progress reports, technical reports, journal articles, books, and patent documents). What is particularly useful for their model is

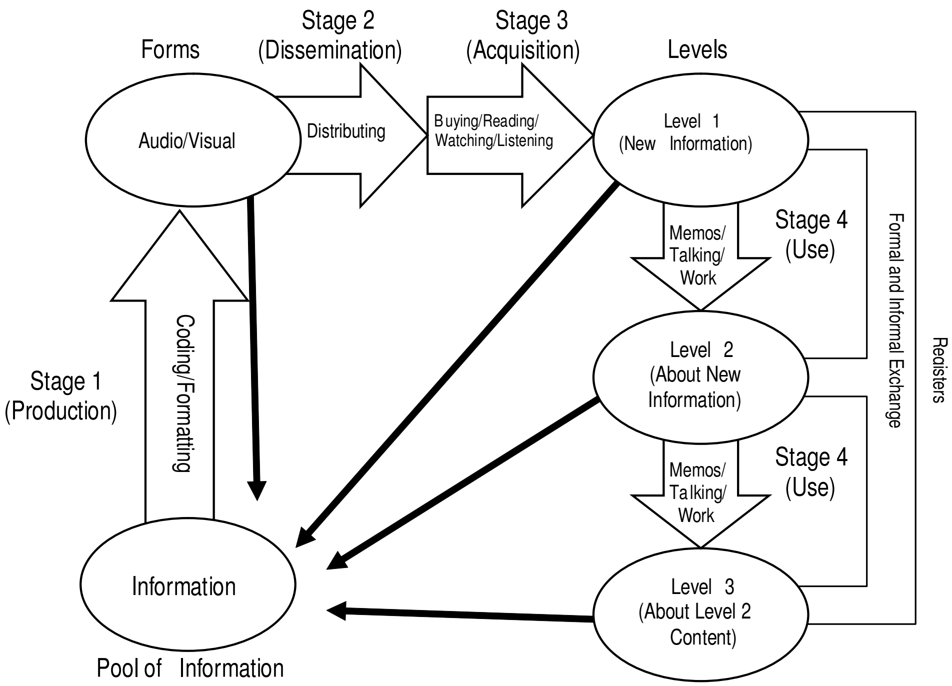

Figure 2.1 Scientific Information Transfer System Model. *Source:* Derived from SCATT Report.

that they observed time frames for the flow of specific information content through these channels from the time of creation to the time the information is reported by such means as laboratory notebooks, informal correspondence or interpersonal discussions, conference presentations and papers, research reports, dissertations, journal articles, patents, books, bibliographic entries, and state-of-the-art reviews. The schema in Figure 2.2 depicts a rough time frame of occurrence on the vertical axis (from the top down). However, less well documented in this context is the timeframe during which the information is obtained and applied by users as opposed to its first appearance in publications (Tenopir and King, 2000a).

Bear in mind the different aspects of communication and different channels of communication when exploring the interaction of information process cycles with communication systems. Scholarly journals are a useful example for demonstrating how these two phenomena interact, because they are a well-established method of formally communicating new information generated through research. Scholarly journals, like most well established products, became well-established because they work. Examining the development of something can give insight into the nature of the problem that it is designed to solve, so we offer a very short history of the scholarly journal. A more extensive history of print and electronic journals can be found in Tenopir and King (2000a) and Pullinger and Baldwin (2002).

2.3 MODELS OF SCHOLARLY JOURNALS

In the early stages of science, the scholars and practitioners were either dispersed over a wide geographic area or gathered in a few small areas. They usually communicated either face to face or in letters, which may or may not have circulated. As the number of scientists increased during the seventeenth century, scientific societies developed, designed to facilitate the exchange of information between members, even across national boundaries. These societies began to formally publish and distribute materials dedicated to their field. The scholarly journal soon became the centerpiece of the scientific society. As the numbers of scientists increased and the fields of study diversified, so did the scholarly journals. There was a marked increase in interdisciplinary science during the twentieth century because many of the sciences

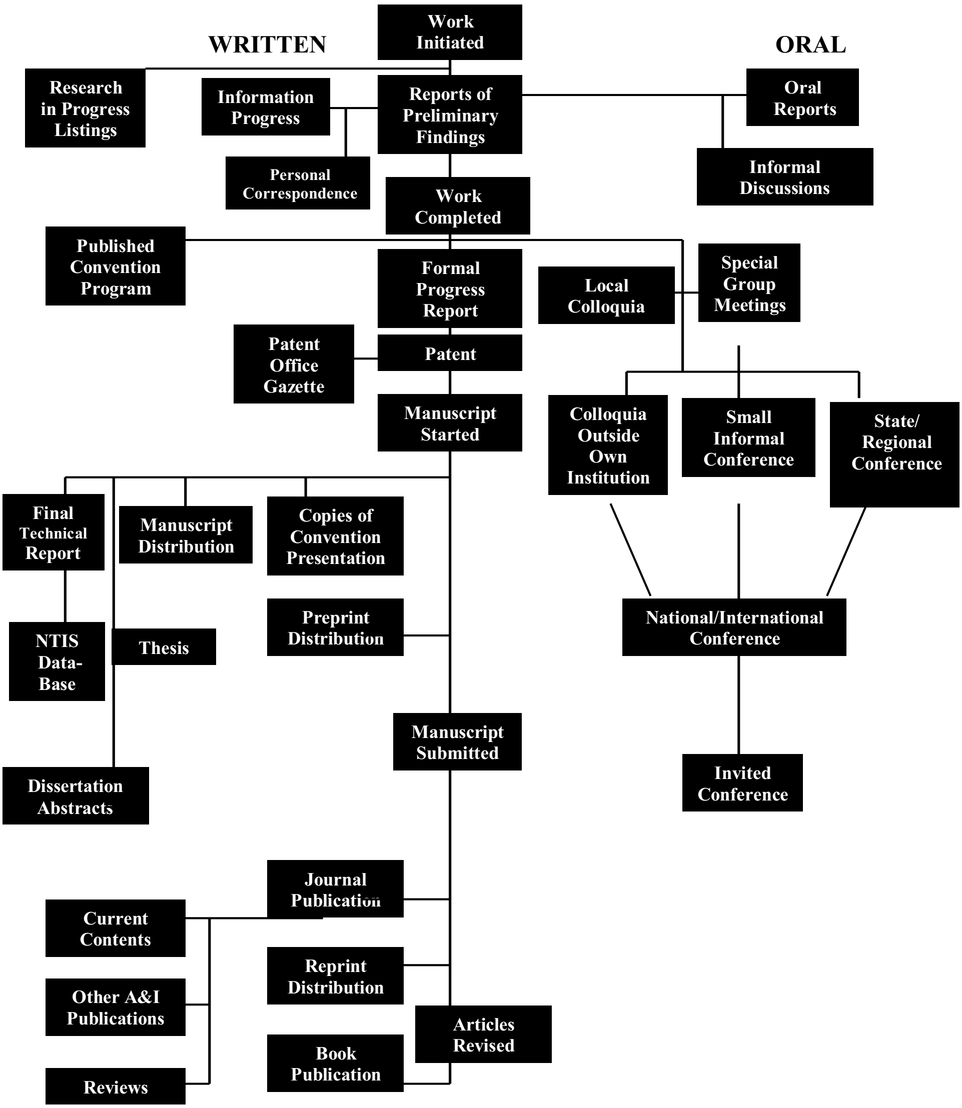

Figure 2.2 Communication Means. *Source:* Adapted from Garvey, Lin and Nelson (1970); Lin, Garvey, and Nelson (1970); and Garvey and Griffith (1972).

became more applied and were brought to bear on complex issues, for example, maintaining a viable natural environment while building habitats suitable for people. The elements that must be taken into account during an environmental impact study are diverse, lying outside a single field; therefore scientists and engineers from different fields had to collaborate. This trend shows no signs of slowing down, and has become increasingly global in nature. Collaboration remains the watchword of the twenty-first century and communication efficiency is as important today as it was in the seventeenth century.

The function of a scholarly journal is to package new, edited, and peer-reviewed information so that it can be transferred from one scientist to another, or to many. Several works can be collected and packaged according to type of content, which allows a journal to be tailored to the interests of its target audience. Packaging articles this way cuts the costs of delivery. Since the journals typically record both the works and the names of authors, they protect against plagiarism and enable recognition and prestige to authors and their institutions. The peer review facilitates trust and editing helps ensure quality. Because journals are widely distributed, it is less likely that information will be altered or lost. Authors who subject their work to the scrutiny of others are more likely to be conscientious in their research and disciplined in their writing, which leads to a higher standard of quality of information.

Scholarly journals have changed dramatically since their inception in the seventeenth century. The journal system became more complex, involving a number of specialized system functions and participants whose role in the system was to perform the functions. To depict these functions and participants, a spiral of the life cycle of information content in scholarly journals was developed as shown in Figure 2.3 (King, McDonald, and Roderer, 1981).

The spiral includes 11 functions, beginning with research and other sources of information creation (1). This function is the role of engineers and scientists. As a result of research, development, and other means of creating information, article manuscripts are composed (2) by engineers and scientists. The composition function refers to formal writing, editing, and reviewing of the manuscripts. When a manuscript is in a form to be communicated, it is recorded (3). These two functions are the role of authors, publishers, editors, and reviewers. At this stage authors have, as yet, very little impact on the scientific and engineering communities by means of formal communication. Only when the work has been reproduced and distributed does it gain the potential for widespread influence on an audience.