Scientific Collaboration: A Synthesis of Challenges and Strategies

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Introduction

Scientific collaboration continues to increase in frequency and importance. It has the potential to solve complex scientific problems and promote various political, economic and social agendas, such as democracy, sustainable development, and cultural understanding and integration. Bibliometric studies over the past two decades have shown a continuous increase in the number of coauthored papers in every scientific discipline as well as within and across countries and geographic areas (e.g. see Grossman, 2002; Wagner & Leyesdorff, 2005; Cronin, Shaw & LaBarre, 2003, 2004; Cronin, 2005; Moddy, 2004; National Science Board, 2004)[1]. Subauthorship, as measured by the number of colleagues thanked in acknowledgement sections of papers, has also consistently increased (Cronin, 2005; Cronin, et al 2003, 2004). In general co-authored publications are cited more frequently than single authored papers (Persson, Glänzel & Danell, 2004). Increasingly, public and private research funding agencies require interdisciplinary, international and inter-institutional collaboration. Examples include the National Science Foundation Science & Technology Center (http://www.nsf.gov/od/oia/programs/stc) and Industry University Corporative Research Center (http://www.nsf.gov/eng/iurcc)programs, and the European Commission Sixth Research Framework (http://europa.eu.int/comm/research/fp6/index_en.cfm?p=0).

As a research topic, scientific collaboration is discussed in diverse disciplines including information science, psychology, management science, computer science, sociology, research policy, social studies of science, philosophy, and in each discipline in which scientific collaboration occurs. In some instances, specialized communities that focus on specific aspects of collaboration have emerged. For example, scientometrics investigates patterns of collaboration using quantitative methods such as co-authorship statistics. This research can be found in journals such as *Scientometrics* and *JASIS&T* as well as in conference proceedings of the

[1] The rate of increase and total percentage of papers coauthored differs between disciplines, ranging from 99% in chemistry (Cronin, Shaw & LaBarre, 2004), 71% in philosophy (Cronin, Shaw & LaBarre, 2003), to 46% in math (Grossman, 2002) and 4% in philosophy (Cronin, Shaw & LaBarre, 2003). It can also differ within disciplines. Moody (2004) found that approximately 50% of all sociology papers are now coauthored, however, this ranges from 8% in Marxist Sociology to 53% in Social Welfare.

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International Society for Scientometrics and Informatrics (ISSI) and American Society of Information Science and Technology (ASIS&T.) The computer-supported cooperative work and social informatics research communities investigate how information and communications technology (ICT) impacts cooperation and work in a variety of contexts, including science. This research is often published in proceedings of the ACM CSCW, ACM GROUP, ACM SIGCHI and ASIS&T conferences, as well as the *ACM TOCHI, CSCW* and *JASIS&T* journals. Research within the domain of social studies of science examines the development of science, technology and medicine, and their social nature. Publication venues include the 4S conference and the journals, *Social Studies of Science* and *Science, Technology & Human Values*. Research policy regarding collaboration can be found in conferences such as the Triple Helix conference and the journals, *Research Policy* and *Science Public Policy*. Thus, there is not one body of literature focusing on collaboration, but rather a strand of literature that cuts across many disciplines and forums.

This large diversity within research on scientific collaboration means that a variety of terminology, research approaches and methods can be found in the research literature. Scientific collaboration is also referred to as research collaboration, R&D collaboration, and team science. Terms used to categorize scientific collaboration include university-industry collaboration, inter-, multi-, trans- and cross-disciplinary collaboration, international scientific collaboration, intradisciplinary or disciplinary collaboration, science-society collaboration, remote and inter-institutional collaboration, large-scale collaboration (big science, teams of teams), and participatory or university-community collaboration (Ziman, 2000.) These categories are neither universally defined nor mutually exclusive. For example, inter- and multi-disciplinary collaboration may be used interchangeably by some authors and defined as different concepts by others. An international scientific collaboration may also be an interdisciplinary collaboration, and it may be difficult to ascertain how each characteristic or the combination contributed to the scientific process. Research methods used to investigate scientific collaboration include bibliometrics, interviews, observations, controlled experiments, surveys, simulations, self-reflection, social network analysis and document analysis.

This variety of terminology and research methods combined with the diversity of publication forums presents unique challenges to understanding scientific collaboration. Students studying collaboration can find it difficult to know where to begin and when to end their literature searches. Researchers may predominantly focus on previous research conducted within their field and may not be aware of results found in other fields, or have a difficult time interpreting the results due to the diversity of research methods used. These challenges, of course, are not unique to scientific collaboration; however, they are perhaps more acute than in other research areas due to their pervasiveness within scientific collaboration research.

This diverse scientific collaboration research literature, including cases of collaboration described in the literature, is synthesized in this chapter. The goal is to increase of our understanding of scientific collaboration. First, terminology and concepts found in the literature are described. Second, the process of scientific collaboration is illuminated by synthesizing research results pertinent to stages of the scientific collaboration process. Collaboration in both the natural and social sciences is included in these discussions; however, research on collaboration in the natural sciences is more prevalent, and this is reflected in the content of the discussions.

No previous ARIS&T chapter focuses exclusively on scientific collaboration; however, several previous chapters focus on components of scientific collaboration. Borgman and Furner (2002), Kling and Callahan (2003) and Kling (2004) discuss scientific publishing, including bibliometrics and emerging socio-technical developments in scientific publishing. Finholt (2002) discusses scientific collaboratories, i.e., internet-based collaboration. Van House (2004) discusses social studies of science, focusing on the construction of scientific knowledge in general. Other ARIS&T chapters discuss issues related to collaboration in general, such as virtual communities (Ellis, Oldridge & Vasconcelos, 2004), organizational knowledge and communities of practice (Davenport & Hall, 2002), and trust and information technology (Marsh & Dibben, 2003).

Terminology and concepts

Defining scientific collaboration: Human behavior, tasks and social settings

Scientific collaboration can be defined as human behavior among two or more scientists that facilitates the sharing of meaning and completion of tasks with respect to a mutually-shared superordinate goal and which takes place in social contexts.

Scientists who collaborate may also bring additional, individual goals to a collaboration (Sonnenwald, 2003a). A typical example is a junior scientist who also wishes to be promoted and receive tenure in addition to contributing to a collaboration. Individual goals can influence a scientist's ongoing commitment to a collaboration and his or her perspective on many aspects of the work.

Tasks within a scientific collaboration often have a high degree of uncertainty, more so than is typically found in other types of work. For example, in research it is typically not clear at the onset that the goal can be achieved or the best way to achieve it. Trial and error is an integral part of the process (Latour, 1987).

Research tasks can be shared among scientists in various ways. Some tasks are divisible and may be performed either sequentially or concurrently (Steiner, 1972; Whitley, 2000). Other tasks may be conjunctive, where everyone must complete the task. For example, in a social science collaboration scientists may jointly develop data collection instruments, separately collect data using the instrument from similar populations in different geographic regions, and then analyze and interpret the results together. In a natural science collaboration, one scientist may suggest a research question and develop data samples. A second scientist may analyze the samples using specialized scientific instrumentation. Research suggests that task demands, available resources, group interaction, the degree of functional dependence among the scientists, and the degree of strategic dependence determine how tasks are allocated and shared among scientists in a collaboration (Steiner, 1972; Whitley, 2000).

Scientific collaboration occurs within the larger social context of science. This context includes peer review, reward systems, invisible colleges, scientific paradigms, national and international science policies, as well as disciplinary and university norms (e.g., see Crane, 1972; Kuhn, 1970; Latour, 1987; Traweek, 1988). It imposes constraints and enables possibilities not always found in other types of contexts, such as the service industry. Characteristics of science contexts are often used in the literature to categorize, or classify, collaborations. The characteristics most frequently referred to are disciplinary, geographic, and organizational. Terminology and concepts related to each are described below.

Classifying scientific collaboration

Disciplinary focus. The terms, intra-, inter-, cross-, multi- and trans-disciplinary collaboration, stress the importance of the role of disciplines in scientific collaboration, and refer to the disciplinary knowledge that is incorporated within a scientific collaboration and produced from a collaboration. Intradisciplinary, or disciplinary, collaboration describes collaboration where each participant has knowledge from the same discipline or field, applies this knowledge within the collaboration which in turn, ideally, produces new knowledge within that same discipline or field.

Interdisciplinary collaboration involves the integration of knowledge from two or more disciplines (Salter & Hearn, 1996; Palmer, 2001). Typically participants come from different disciplines and work together, integrating their knowledge, to produce new knowledge. The terms, multidisciplinary and cross-disciplinary, are sometimes used interchangeably with interdisciplinary collaboration (e.g., Cummings & Kiesler, 2003; Jeffrey, 2003). However, many authors differentiate multidisciplinary and interdisciplinary collaboration defining multidisciplinary collaboration as research that uses knowledge from different disciplines, but does not integrate or synthesize that knowledge (Bruce, Lyall, Tait & Williams, 2004). For example, a collaboration may use methods or scientific instruments that originated from one discipline to investigate a research question that arises in another discipline. The differences between inter- and multidisciplinary research can be difficult to distinguish in practice because integration of knowledge may be subtle and take time to detect.

Transdisciplinary collaboration has been historically defined as the integration of all knowledge or the integration of all knowledge relevant to a particular problem. Recently, this definition has been extended in several ways. It is defined as broad interdisciplinary research that advocates the integration of natural sciences, social sciences and the humanities, and the involvement in multiple stakeholders from all aspects of society (Klein, 2004). A related concept is mode 2 knowledge production in which research questions do not emanate from disciplines but from contexts of use, incorporates heterogeneous skills and knowledge, and involves diverse organizations and social accountability (Gibbons, Limoges, Nowotny, Schwartzman, Scott & Trow, 1994). The involvement of communities in research is also shared with participatory action research (see below).

Geographic focus. The geographic location of scientists participating in a collaboration provides another focus for classifying scientific collaboration. Terms such as remote collaboration, distributed collaboration, scientific collaboratories, and international collaboration emerge in the literature. Remote and distributed collaboration refers to those instances when participants are not collocated. Collocation may be defined in terms of geographic separation of scientists (irrespective of scientists' institutional affiliations) or in terms of scientists' institutional affiliations (where geographic propinquity is assumed, e.g., Bos, Zimmerman, Cooney, Olson, Dahl & Yerkie, in press). The latter is synonymous with inter-institutional collaboration.

The term, scientific collaboratory, originally meant ‘a laboratory without walls’ that allows scientists to conduct research across geographic distances (Wulf, 1993; National Research Council, 1993). Initially scientific collaboratories provided remote access to scientific instruments (Finholt, 2002). The definition and vision of scientific collaboratories have expanded over the years. A current definition is:

> a network-based facility and organizational entity that spans distance, supports rich and recurring human interaction oriented to a common research area, fosters contact between researchers who are both known and unknown to each other, and provides access to data sources, artifacts and tools required to accomplish research tasks. (Science of Collaboratories, 2003).

This definition emphasizes remote collaboration although it does not preclude that some participants may be collocated. It incorporates the concept that collaboratories are socio-technical interaction networks (Kling, McKim & King, 2003).

International scientific collaboration refers to collaboration that occurs when participants work in different countries. It is a special case of remote collaboration, and it includes collaboration among scientists in developed and developing countries which is also referred to as North-South collaboration (e.g., Drake, Ludden, Nzongola-Ntalaja, Patel & Shevtsova, 2000; Olson, Teasley, Bietz & Cogburn, 2002; Duque, Ynalvez, Sooryamoorthy, Mbatia, Dzorgbo & Shrum, 2005). International collaboration crosses international boundaries but may be located within the same cultural region, e.g., the Barents region that shares a common cultural heritage and language but is located in Russia, Finland, Sweden and Norway (e.g., Iivonen & Sonnenwald, 2000). Although cultural differences based on national affiliation or cultural heritage are mentioned in the literature, intercultural scientific collaboration is a term that has not emerged. Perhaps this reflects a bias towards the ideal of a universal scientific culture.

Organizational and community focus. Collaboration across organizational boundaries may include collaboration across geographic distances as well, however, here the focus is on factors that emerge due to differences between academia and business, government and non-government organizations including communities. The terms, university-industry collaboration and academic-industry collaboration, as well as the less-frequently used term, collaborative practice research (Mathiasson, 2002), all refer to collaboration between university scientists and scientists and other professionals working in industry. Science parks that house industrial research offices and labs near or on university campuses is one mechanism to promote collaboration, knowledge transfer and innovation development among industrial and university scientists.

The term, participatory action research, refers to collaborations between scientists and research participants in general; however, a focus on collaboration between scientists and communities, including non-government organizations (NGOs) and citizen groups, has emerged over time (Brydon-Miller, 1997, Fisher & Bull, 2003; Secrest, et al, 2004, Wilson, 1999). Synonymous terms include participatory research, investigator-community collaboration, science-society collaboration and community collaboration. Participatory action research values the knowledge, experiences and values of community members, and seeks to incorporate these into research projects. Its goal is to create new knowledge that leads to effective social action which solves real life problems. Effectiveness of social action is to be determined by participants. Science shops[2] have emerged in Europe to help communities and scientists identify and establish participatory action research projects (Pax Mediterranea, 2003; Leyesdorff & Ward, in press).

Related concepts include the triple helix model of innovation and use-inspired research. The triple helix model of innovation examines relationships between research, industry and government in knowledge based economies (Etzkowitz & Leydesdorff, 2000.) The concept, use-inspired research, proposes a new research paradigm in which science is "directly influenced both by the quest of general understanding and by considerations of use" (Stokes, 1997, p. 79.) Both concepts have influenced public and private research agencies to encourage and sometimes require scientific collaboration as a means to support socio-economic development.

Stages of Scientific Collaboration

The four stages of scientific collaboration - foundation, formulation, sustainment and conclusion - presented in this chapter provide a platform to highlight and understand the complexity of scientific collaboration. The stages are based on an approximate temporal view of the scientific process and correspond to stages suggested by others (e.g., Kraut, Gallagher & Egido, 1988; Maglaughlin, 2003). The stages frame the progressive emergence of factors that impact collaboration during the scientific process. However, scientific collaboration is a dynamic process. New research questions or topics may emerge during any collaboration due to external and internal forces, and may require many changes in the collaboration. Similarly new partners may join a collaboration at various points in time, and formulation issues may then re-emerge as important. Individuals and organizations who wish to facilitate and conduct scientific collaborations should not ignore these dynamics.

In the following sections, research results that emerged from different contexts or settings of scientific collaboration relevant to each stage are synthesized. Although the results emerged from specific contexts, and this is acknowledged in the text, some results are similar across contexts and others may be applicable in additional contexts. For example, findings regarding the need to provide training opportunities for local staff can be found in research on university-minority community collaboration (Fisher & Ball, 2003), collaboration between research intensive and historically minority universities in the USA (Adessa & Sonnenwald, 2003), and between universities in the developed and developing world (Oldham, 2005). Similarly, the finding that remote collaboration requires and benefits from explicit identification of task responsibilities in the formulation stage (Olson, Olson & Cooney, in press) may be useful when considering collocated collaboration as well. All lessons learned applicable to one of the stages in the collaboration process are discussed within that stage to allow readers to consider the lessons learned as plausible strategies or areas of further investigation.

Foundation Stage

[2] See http://www.scienceshops.org for more information about science shops.

The foundation stage focuses on factors which provide or impact the foundation for collaboration, i.e., factors that are required for collaborations to be considered and subsequently initiated, or which can prohibit collaborations from being considered and initiated. This stage may also be viewed as a pre-history stage which includes knowledge, norms, policies and relationships that exist before a collaboration is formulated. Five categories of factors: scientific, political, socio-economic, resource accessibility, and social networks and personal factors, emerged from a synthesis of the literature.

Scientific Factors

The opportunity to discover new knowledge and solve complex problems in a timely manner motivates many scientists to consider collaborating. For example, when the World Health Organization (WHO) issued a global alert concerning the health threat posed by SARS, scientists began to collaborate to find the cause of the disease and develop a cure. Five weeks after the global alert was announced, Dr. David Heyman, executive director of WHO Communicable Diseases program commented: "The pace of SARS research has been astounding. Because of an extraordinary collaboration among laboratories from countries around the world, we now know with certainty what causes SARS." (as quoted in WHO, 16 April 2003).

Increasing specialization within science, the increasing complexity of scientific instruments, and the need to combine different types of knowledge and expertise to solve complex problems can also motivate and provide a foundation for collaboration (Katz & Martin, 1997). No longer can a single scientist conduct some types of research. For example, within high energy physics there is no single investigator research. Research is conducted by large teams of several thousand, with each team member making a specific type of contribution[3] (Hofer, McKee, Birnholz & Avery, in press; Traweek, 1988).

Scientific collaboration can also help extend the scope of a research project and foster innovation because additional expertise is made available (Beaver, 2001; Lambert, 2003; Cummings & Kiesler, 2003). It can increase scientific reliability and the probability of success because more than one person is considering the accuracy, quality and meaning of the results (Thagard, 1997; Beaver, 2001). It may lead to new branches of sciences and new careers within the frontiers of science (Cummings & Kiesler, 2003). Collaboration can also increase a scientist's credibility, because collaboration is viewed as a form of acceptance, or a rite of passage, within the scientific community (Mervis & Normile, 1998; Hara, Solomon, Kim, & Sonnenwald, 2003).

There are potentially negative aspects of scientific collaboration as well. There are concerns that collaborations are sometimes used to hide unethical conduct. For example, collaborations between advanced and developing countries may occur in order to conduct unethical clinical trials, biological warfare experiments, and investigations involving natural resources that are prohibited in advanced countries (Oldham, 2005). In other instances, scientists may collaborate with others for the purposes of intellectual espionage and scooping of results (Beaver, 2001).

Wray (2002) discusses additional concerns. There can be a diffusion of epistemic and ethical responsibility. When many scientists collaborate, no one scientist may feel responsible for the

[3] A recent co-author list of a high energy physics paper had 1,699 names (Hofer, McKee, Birnholz & Avery, in press.)

work. Collaborations may become powerful lobby groups, influencing research policy and funding decisions in their favor. When this occurs, the balance between single investigator and collaborative research funding may become skewed with single investigators not receiving funding.

Collaborations may also hinder individual's career advancement, especially for junior scientists. Tenure committees may undervalue a junior scientist's contribution to research conducted with a well-known, senior scientist. When junior scientists have special expertise that is in demand, and they accept many offers to collaborate, their research may become fragmented and it may be difficult for them to develop their own research program (Burroughs Wellcome Fund, et al, 2004). The brochure, *Making the Right Moves* (Burroughs Wellcome Fund, et al, 2004), offers a checklist of items for junior scientists to consider before entering a collaboration.

Political Factors

National and international politics are influenced by - and influence - scientific collaboration. Informal and formal scientific collaboration can increase understanding between countries and promote world peace even when relationships are strained between countries (De Cerreño & Keynan, 1998; Nature, 2002). For example, during the Cold War, scientists in the USA and USSR established and maintained relationships which were valuable in promoting the end of the Cold War (US Office of Science & Technology Policy, 2000). Another example is the International Arids Lands Consortium (http://ag.arizona.edu/OALS/IALC/Home.html). Its scientific goal is to explore problems and solutions that emerge in arid and semiarid regions. Its political goal is to be a catalyst for peace (McGinley & Charnie, 2003.) Partners include universities and research organizations in the USA, Egypt, Israel and Jordan. The consortium sponsors collaborative research projects that include scientists from these countries, including the Wayne Owens Peace Fellowship Program.

Scientific collaboration may also help heal post-war wounds (Arunachalan & Doss, 2000), and help re-direct military research into peace-time applications (US Office of Science & Technology Policy, 2000). For example, the International Science and Technology Center (http://www.istc.ru) supports former weapons researchers in Russia and the Commonwealth of Independent States to collaborate with scientists worldwide in non-military projects.

Countries also use scientific collaboration to promote political unity within a country or region (Banda, 2000). For example, during the past decade the European Science Foundation's research programs require scientific participation from at least three countries in the European Union (EU) and associated states in an effort to increase understanding between countries. When political barriers are removed between countries, there is an increase in scientific collaboration between the countries, as measured by co-authorship and joint projects (Havemann, 2001; Williams, 1998).

National and international political situations and policies may also hinder scientific collaboration. For example, scientific collaborators left Rwanda in 1994 when genocidal mass murders occurred and many remain reluctant to return (Cohen & Linton, 2003). In 2002 research on AIDS conducted by scientists at the Center for Disease Control (USA) and NGOs in Myanmar (formerly Burma) was halted by the U.S. government when the Myanmar government prohibited NGOs from performing voluntary counseling and testing (Cohen & Linton, 2003). Recent changes in the U.S. national security policy are also hindering collaboration. Some scientists cannot attend conferences and meetings in the U.S. due to visa delays; if a foreign scientist leaves the U.S., he or she may not be able to return; and restrictions can be placed on U.S. government funding contracts regarding publication of results classified as "sensitive but not classified" (Gast, 2003).

Establishing collaborations among nations where official relationships are strained can be challenging as national policies and funding mechanisms may not be in place to support such efforts. To address this challenge, scientists are encouraged to: benchmark previous and ongoing achievements; identify global scientific problems that are important to satisfy a national need in each country; and specify how funds can address these problems (Nature, 2002; Mervis & Normile, 1998.) Three-way collaborations that include one partner from a 'neutral' country are encouraged, as are conferences to share ideas and develop projects, and training opportunities (Nature, 2002).

When collaborations are established solely in response to political forces, they are seldom successful[4]. Velho and Velho (1996) describe one such collaboration between U.K. and Brazilian scientists that their respective governments promoted despite objections by the Brazilian scientific community. Agreements regarding access to and handling of resources were not honored, local scientists were excluded, and co-authorship among scientists from the two participating countries was minimal. When such collaborations occur between advanced and developing countries, perceptions of scientific and economic imperialism emerge (Velho & Velho, 1996).

Socio-economic Factors

Scientific collaboration has been called a "springboard for economic prosperity and sustainable development" (US Office of Science & Technology Policy, 2000). In the near-term businesses can realize economic benefits from collaboration through research and development tax credits and access to public research funding otherwise not available to them (Lambert, 2003; Autio, Hameri & Nordberg, 1996). This latter is achieved by collaborating with universities in government-sponsored industry-university research programs.

In the long-term collaboration can spread the financial risk of research for businesses, as well as provide access to local and scientific markets, motivate a company's workforce, and provide access to students and scientists for employment recruitment purposes (Grey, Lindblad, & Rudolph, 2001; Lambert, 2003; Autio, Hameri, & Nordberg, 1996). Companies can often hire scientists in developing countries at salaries rates that are one-tenth of the salary rates in advanced countries but ten times the local rates (Oldham, 2005).

Countries also look to collaboration to support national and regional economic development. Many countries have research programs that require collaboration between universities and industries, including small medium enterprises. For example, the Swedish agency, VINNOVA (http://www.vinnova.se), was established to support national and regional innovation and

[4] The various types of success that may emerge from a collaboration are discussed below in the section, definitions of success.

economic growth through collaboration between academia and industry. It requires all research proposals to include both academic and business participants.

In comparison, developing countries tend to realize a larger return on investment in science when portions of their research funding are spent to support collaboration with scientists in advanced countries (Oldham, 2005; Arunachalan & Doss, 1999). Such collaborations can provide advice, key lab materials, equipment, student and staff training, and research project funding which help to increase the return on investment (TWAS, 2004).

Universities can also benefit from funded collaborative research, but there can be disagreements regarding the distribution of overhead funds associated with collaborative research grants (Maglaughlin & Sonnenwald, 2005).Typically the largest share of overhead monies is allocated to the university and department that is the lead or primary grantee, and thus each university and university department wishes to be the lead. This can hinder and even prohibit collaboration with scientists who work at universities and departments known to have inflexible policies regarding overhead.

National policies that limit access to financial resources can also constrain collaboration. Smith and Katz (2000) point out that the university ranking system in the U.K. constrains university-industry collaboration in some instances. New universities and ones with lower research assessment evaluations (RAE) rankings cannot apply for research funding or research student fellowships. However, these universities often have the strongest links to small and medium enterprises and could easily form collaborations with them. Their only solution is to allow a highly ranked university be the lead on the grant application.

Resource Accessibility

Scientific collaboration is often motivated by the need to gain access to expensive instruments, unique scientific data, scarce natural and social resources, and large amounts of scientific funding (Wagner, Staheli, Silberglitt, Wong & Kadtke, 2002; Wray, 2002; Birnholz & Bietz, 2003; Katz & Martin, 1997). For example, the William R. Wiley Environmental Molecular Sciences Laboratory (EMSL, http://www.emsl.pnnl.gov) at the Pacific Northwest National Laboratory as well as National Computing Center Resources (NCRRs) established by the National Institutes of Health invite scientists to collaborate with them (Kouze, Myers, & Wulf, 1996; Chin, Myers & Hoyt, 2002; NCRR Biomedical Collaboratories Workshop Report, 2001). The visiting scientists typically bring research questions and biological samples; the centers provide expertise on and access to specialized instruments that are used to analyze the samples to answer the research questions. Human geneticists may collaborate in order to get access to unique reagents, clones and probes and family resource data (Atkinson et al, 1998). Biologists collaborate to gain access to natural resources such as rain forests which may be located in politically sensitive areas (Velho & Velho, 1996; Oldham, 2005). The National Science Foundation, European Science Foundation and other funding agencies often require groups of scientists either within the same discipline or from different disciplines to collaborate to help ensure expensive instruments are used frequently. Some scientific instruments are so expensive that funding from multiple agencies and countries is needed to finance then. For example, fifty-six countries contribute to the construction and operation costs of particle accelerators, such as the new large hadron collider (LHC) located at CERN (http://public.web.cern.ch/Public/Welcome.html). These types of large collaborations have not emerged in disciplines that do not require such expensive resources.

Collaboration is typically more successful when each participating scientist provides and receives resources - even when the participating scientists come from different countries and disciplines. For example, when African and non-Africans have successfully collaborated in medical research, Africans provided access to local communities and non-Africans provided free treatment, lab equipment and training (Cohen, 2000; Bietz, Naidoo, & Olson, in press). Collaboration between China and Taiwan is proceeding despite political differences, because Taiwan provides experienced, mid-career scientists that China lacks due to the Cultural Revolution, and China provides a large number of younger scientists to increase the size of Taiwan's scientific community (Normile, 2003).

Social Networks and Personal Factors

Social networks and personal factors provide a foundation for collaboration. Social networks may span disciplinary, organizational and national boundaries. Collaboration frequently emerges from and is perpetuated through social networks. For example, the 'small network' phenomenon has been observed with respect to scientific collaboration. Two scientists are more likely to collaborate and co-author a paper if they have a co-author in common (Newman, 2001). When studying the one million scientists in the biomedical research community who publish in MEDLINE, Newman (2001) found that the typical distance between any two randomly selected scientists was approximately six links. That is, you can reach any one scientist from another by following about six co-authorship linkages. There may be more than one shortest path between scientists, and scientists in the same field may be linked through scientists in other fields (Newman, 2004).

Scientists look to their social networks for ideas regarding new research projects and to identify and select collaborators (Beaver, 2001; Bozeman & Boardman, 2003; Crane, 1972; Katz & Martin, 1997; Maglaughlin & Sonnenwald, 2005; Traweek, 1988). Personal factors play a role in establishing and sustaining social networks and subsequently collaborations. Personal compatibility, including similar approaches to science, similar working styles, mutual respect, trust and the ability to get along and enjoy one another's company are also used to identify and select collaborators (Creamer, 2004; Hara et al, 2003; Maglaughlin & Sonnenwald, 2005). Scientists also describe successful collaborations as fun, and use dating and marriage analogies when describing successful relationships (Maglaughlin & Sonnenwald, 2005).

Cultural heritage influences social networks and personal relationships. For example, there tends to be more collaboration between scientists in countries with historical ties, such as colonial ties (Wagner & Leyesdorff, 2005). Typical collaborations in computer science within China include one or two students with an elder scientist, reflecting the cultural pattern of an elder mentoring the young and the Cultural Revolution when no student was educated to become a scientists resulting in no mid-career scientists today (Liang, Guo, & Davis, 2002). Traweek (1988) describes how cultural differences between American and Japanese high energy physicists had a negative impact on their collaboration. The participating scientists, however, did not recognize that their problems stemmed from cultural differences. They mistakenly believed their membership in the same research community eliminated cultural values and practices.

Gender may also play a role in social network formation and collaboration. In a survey of researchers at elite national research centers, Bozeman and Corley (2004) found that 83.33% of the scientists who collaborate with non-tenure track women are other women. Overall, men in their sample had an average of 14.04 collaborators and women an average of 12.02. Yet many women scientists do not work at elite research centers. Eisenhart and Finkel (1998) found that women scientists chose non-elite scientific places of work because these places offer alternatives to the impersonal and inflexible practices that characterize elite science. We know that status plays a role in science (Kuhn, 1970); we do not know how gender in conjunction with status impacts social network formation and collaboration.

Social networks can be expanded through informal, chance meetings and formal meetings and activities (Beaver, 2001). It is sometimes said that universities should only have one water cooler or one coffee machine, so scientists will meet and get to know one another informally. Informal meetings can lead to collaboration (e.g., see Lambert, 2003). Formal meetings can also lead to collaboration. Research centers often host seminars and events that bring scientists together can help build social networks. For example, the London Technical Network has activities that bring together scientists from industry and universities in order to foster collaboration (Lambert, 2003).

Social networks have been analyzed to identify areas of strengths and weaknesses within and between research organizations and institutions, businesses and countries in order to direct scientific development and funding policies (e.g., Parent, Bertrans, Côté, & Archambault, 2003; Owen-Smith, Riccaboni, Pammolli, & Powell, 2002.) Bibliometric analyses of co-authorship, co-citation and acknowledgement patterns as well as sociometric surveys in which scientists identify their collaborators are used in such analysis. Thus social networks impact collaboration in multiple ways.

Formulation Stage

During the formulation stage, scientists initiate and plan collaborative research projects. Collaborative research is not divorced from traditional scientific norms and practices. However, because it involves multiple scientists, some of who may have different disciplinary backgrounds, work in different institutions, and are not collocated, additional planning and additional time for planning is required for success. The literature suggests that: research vision, goals and tasks; leadership and organizational structure; use of information and communications technology (ICT); and intellectual property and other legal issues need to be considered in greater detail than in single investigator research.

Research Vision, Goals and Tasks

A vision and complex problems can motivate scientists to collaborate (Olson, Olson & Cooney, in press; Schiff, 2002; Sonnenwald, 2003b). As mentioned earlier, the identification of the cause and methods of halting the spread of SARS disease in order to stop a global health threat motivated scientists to collaborate. Dr. Klaus Stöhr, coordinator of the SARS collaborative effort, observed: "The people in this network [collaborating on SARS] have put aside profit and prestige to work together." (as quoted in WHO, 16 April 2003). Research visions and goals often appear obvious and straightforward after they have been achieved or are close to being achieved, though in the early stages of formulating a collaboration, visions and goals can be difficult to articulate. This difficulty emerges to some degree when formulating any new research question (as many Ph.D. students have experienced.) However in collaborative research the visions and goals are often scientifically more complex than those tackled by single investigator research, and require buy-in by all scientists who have the expertise and other resources needed to achieve the vision. Personal motivation and excitement regarding a vision and research goals can help scientists overcome other challenges that emerge when conducting research collaboratively.

Due to their complexity, visions and goals may require buy-in from other stakeholders as well, including participating institutions, one or more funding agencies, and citizen and community groups. Articulating clear visions and goals that multiple individuals and groups can understand and support is a skill scientists need when initiating large and complex scientific collaborations.

In addition, research tasks should be clearly defined and owned by individual scientists. This is particularly important when the collaboration occurs across distances (Maglaughlin & Sonnenwald, 2005; Olson, Olson & Cooney, in press). When scientists are collocated they can informally observe and discuss task progress, but this is more difficult to do across distances and disciplines, and therefore defining tasks and task responsibility from the onset is important.

Language and epistemological differences can hinder the formulation of visions, goals and tasks (Jeffrey, 2003; Traore & Landry, 1997; Maglaughlin & Sonnenwald, 2005; Olson, Olson & Cooney, in press; Palmer, 2001). Disciplines and subfields use specific terminology that varies across disciplines. The same term may have different meanings in different disciplines, and different terms may have the same meaning. Research methods also vary across disciplines, and scientists may not know what they do not know. A material scientist may not know that it can take a biologist 6 months or longer to create a biological sample. A chemist may not know that it can take a sociologist 6 months or longer to analyze ethnographic data. The biologist and sociologist may not realize that others do not know these things because it is common knowledge in their disciplines. Disagreement and conflict may emerge when scientists have misconceptions regarding the resources, including time, required to conduct various research tasks.

When scientists collaborate with others from different types of organizations, universities, communities and countries additional challenges may emerge from differences regarding what constitutes a research goal, realistic tasks and task completion timeframes, and ethical practices as well as from participants' previous negative experiences and feelings of distrust. Businesses may want research goals and tasks to be more pragmatic, directly contributing to new and existing products, services and practices, whereas scientists may want the goals to have a longer-termed focus (Mathiassen, 2002). Historical black and minority colleges and universities in the U.S. typically do not have the same resources to support research as found at research intensive universities. Infrastructure services, such as purchasing, accounting and computer support, scientific equipment, time dedicated to research, as well as trained graduate students and postdoc fellows are often less available (Adessa & Sonnenwald, 2003). Groups that have experienced historical trauma and prejudice, such as Native American Indians and African American communities, may distrust scientists, and scientists may exhibit bias and ignorance when formulating research goals and tasks involving such groups (Fisher & Ball, 2003; Secrest, et al, 2004). Developing countries may not want scientists from advanced countries to remove biological specimens from their countries, and scientists in advanced countries may see this as a natural or necessary activity (Velho & Velho, 1996).

To help manage these issues scientists can include participants and stakeholders in this stage from the participating organizations and communities (Fisher & Ball, 2003; Cohen, 2000; Secrest et al, 2004). For example, when establishing a collaboration with tribal communities, Fisher and Ball (2003) worked with the community for two years to plan their research project. A facilitator assisted them, helping to elucidate and negotiate scientists' and tribal perspectives and expectations. The Tribal Council, the local controlling authority, retained the right to approve or disapprove project activities and control of the research data. A tribal research code (in addition to the university research code), a culturally specific assessment, and intervention methods were developed. Plans were made to employ and train community members as project staff. These staff members later became ombudsmen for the research within the community, helping to establish trust and cooperation. Some communities may have established research codes and practices but many have not, and in those communities scientists need to identify the social authorities and work with them. In some instances the social authorities may be local church groups, mothers in the community, or workers' union. Holding focus group sessions with these groups can help researchers learn more about the values, expectations and language of the community and to receive feedback on materials to be used in the research (Secrest, et al, 2004).

Additional best practices include sharing information about budgets (Cohen, 2000); ensuring that everyone receives benefits from the collaboration (Olson et al, in press); developing a shared statement of principles, expected benefits and mutual obligations (Cohen, 2000); developing a shared vocabulary (Olson, Olson & Cooney, in press); ensuring differences in resources are accounted for and aligned (Adessa & Sonnenwald, 2003), and establishing community and scientific advisory boards (Secrest et al, 2004; Sonnenwald, 2003b).

Leadership and Organizational Structure

Studies of successful collaboration show that leadership is important for success (Olson et al, in press; Schiff, 2002; Stokols, Harvey, Gress, Fuqua, & Phillips, 2005). Collaborations are more successful when leadership has project management experience and is respected by participants (Olson et al, in press.) Some large collaborations have hired professional managers to be part of the leadership team, and consultants to provide leadership and managerial training. Leadership, including scientific, financial and administrative leadership, may be shared among several individuals to take advantage of individual strengths and to help ensure that no one scientist is over burdened by leadership responsibilities (Sonnenwald, 2003b).

Collaborations can be organized in different ways. Chompalov, Genuth and Shrum (2002) studied 53 inter-institutional scientific collaborations in physics and allied sciences to identify how collaborations are typically organized. Four types of organizations emerged from their analysis: bureaucratic, leaderless, non-specialized and participatory.

Bureaucratic collaborations have a "hierarchy of authority, written rules and regulations, formalized responsibilities, and a specialized division of labor." (Chompalov, et al, 2002, p. 756.) Bureaucratic collaborations typically also have extensive external evaluations, numerous committees and boards, and officially appointed project leaders. A history of competition among participants and the large amount of money involved has led to the bureaucratic organization format (Warnow-Blewett, Genuth & Weart, 2001).

Leaderless collaborations have administrative but no scientific leaders (Chompalov, et al, 2002). The administrator leaders solicit input from scientists, and put scientists in charge of specific projects. These collaborations also have a board of directors with ultimate authority and formal rules and regulations for participation. These collaborations operate well when there is collegiality among scientists and the collaboration staff.

In non-specialized collaborations there is hierarchical management but less formalization and differentiation of roles and responsibilities (Chompalov, et al, 2002). Multiple teams perform similar tasks, e.g., analyzing different data sets using identical, standard algorithms. In these collaborations, scientific leadership is needed to establish and maintain standards. Administrative tasks are shared among members.

Participatory collaborations are egalitarian in that there is no one scientific or administrative leader (Chompalov, et al, 2002). There are no formal rules and regulations but rather non-binding memos of understanding. Members publish results collectively reflecting a lack of competition over intellectual property. These collaborations are primarily found in particle physics. Several characteristics of particle physics contribute to the viability of this type of organizational structure. Particle physicists are widely dispersed across universities, and require highly specialized and complex equipment that requires many types of expertise and large amounts of funding to design, develop and operate. No one person or group can solely procure the necessary resources to conduct science under these conditions. A consensual, participatory approach is needed.

Chompalov, Genuth and Shrum's work certainly contributes to our understanding of the organization of collaborations. Their study, however, focuses on natural science collaborations that occur among elite research institutions in advanced countries. Additional research focusing on collaborations in different disciplines, institutions and countries may yield additional insights regarding effective organizations.

Information and Communications Technology (ICT)
Research continues to demonstrate that the introduction of information and communications technology (ICT) that does not complement, or is compatible with, existing policies and practices will not increase scientific collaboration (e.g., Duque, Ynalvez, Sooryamoorthy, Mbatia, Dzorgbo & Shrum, 2005; Star & Ruhleder, 1996; Sooryamoorthy, Duque, Ynalez & Shrum, under review). Yet ICT can facilitate scientific collaboration and give rise to new types of collaboration, especially when scientists can not and, even perhaps, should not be collocated. For example in developing countries ICT can support the "migration of minds without the migration of bodies" (Oldham, 2005). Bos and colleagues (in press) have identified seven forms of remote scientific collaborations based on their use of ICT. The seven categories are: shared instrument systems, community data systems, open community contribution system, virtual community of practice, virtual learning community, distributed research centers and community infrastructure projects. Each category is made possible or enhanced through the use of ICT.

ICT applications used to support collaboration include e-mail, instant messaging/chat, listservs, video-conferencing, voice over IP (VOIP), WIKIs, blogs and other type of web pages, shared applications (e.g., to support synchronous data analysis), electronic lab notebooks, shared remote access to instrumentation, shared electronic whiteboards (e.g., used during video conferences to support information sharing and knowledge construction), project management tools, scheduling/calendar tools to schedule experiments in labs as well as meetings, manuscript submission and review systems, and digital libraries and shared data repositories, including thesauri, meta-data and information retrieval tools. For an in-depth review of ICT used in remote scientific collaboration see Hofer, Bos, and Olson (in press).

To be adopted and used within any setting, including scientific collaboration, ICT should provide benefits over current practices, be compatible with scientists' values, experiences and needs, be easy to learn how to use, easy to try out, and/or its results easily seen (Rogers, 1995). ICT can impact research tasks in unexpected ways, and a participatory design process in which technology and work practices are co-designed may be needed. For example, Sonnenwald and her colleagues (2002) found that the introduction of video-conferencing and an electronic whiteboard during group meetings increased the level of formality in those meetings which decreased the effectiveness of the meetings. Changes to the implementation and operation of the video-conferencing technology as well as to the meeting format and content explicitly adding and supporting informal interaction during the meetings were developed in collaboration with technical staff and scientists. The results increased the effectiveness of the meetings.

Disciplines, institutions and countries tend to adopt ICT at different rates (Walsh & Bayma, 1996; Walsh, Kucker, Maloney, & Gabbay, 2000; Kling & McKim, 2000; Duque, Ynalvez, Sooryamoorthy, Mbatia, Dzorgbo & Shrum, 2005). For example, physics and math began using e-mail in 1988 and 1989, and biologists began using it in 1992 (Walsh, et al, 2000). Differences in adoption rates among disciplines may be attributed to the nature of research in those disciplines. For example, Birnholtz and Bietz (2003) propose that sharing data via ICT is easiest in disciplines where there is low task uncertainty and high mutual dependency, including consensus on the types of problems to be researched. Examples include Genbank and Inter-university Consortium for Political and Social Research. Barriers to data sharing include competition, and a large amount of work involved to make data re-usable when compared to the benefits and risks of sharing (Birnholz & Bietz, 2003). E-mail is still being introduced in many developing countries, and its use in collaboration appears to be primarily influenced by organizational and social factors (Duque, Ynalvez, Sooryamoorthy, Mbatia, Dzorgbo & Shrum, 2005)

ICT tools may be adopted at rates and initially used in different ways, yet over time consensus and convergence of use appears to emerge. Walsh, Kucker, Maloney and Gabbay (2000) found that between 50% and 65% of sociologists, biologists, mathematicians and physicists surveyed (in developed countries) used e-mail as their first choice to share conference information and meeting agendas, coordinate schedules, ask/answer a quick question, solicit input for a decision, and give progress updates. On average only 13% chose to use e-mail to support social interaction.

Scientific collaboration continues to inspire innovations in ICT. The needs of scientific research today continue to motivate areas of research and development in ICT. Research programs such as the cyberinfrastructure program the U.S. (Atkins, et al, 2003; Berman & Brady, 2005) and e-science and e-social science programs in the U.K. (U.K. Research Council e-Science Core Program, 2005; Hey & Trefethen, 2003) are funding development in ICT to support the needs of remote scientific collaboration, including applications that support collaborative, synchronous access to remote scientific instruments (e.g., Sonnenwald, Maglaughlin & Whitton, 2004), the possibility to securely and quickly transport billions of terabytes of scientific data among scientists around the world[5], and to enable secure high-speed distributed computation needed to construct complex scientific models and 3D telepresence environments (e.g., Welch, Fuchs, Cairns, Mayer-Patel, Sonnenwald, Yang, State, Towles, Ilie, Ampalam, Krishnan, Maurin, Noel & Noland, in press). Papers presented at the First International Conference on e-Social Science (http://www.ncess.ac.uk/events/conference/2005/papers/) and Berman and Brady (2005) provide additional examples of current and future ICT to support e-social science and e-science projects. Security, data integrity, very high-speed telecommunications and computation, data privacy, effective retrieval (especially across multiple disciplines each with their unique terminology), and long-term archival access are several of the technical challenges facing these project.

Reconciling the emerging cyberinfrastructure with social aspects of the scientific process may prove to be extremely challenging (David, 2005). The design of new ICT infrastructure and applications will continue to benefit from research on social aspects of collaboration. A new area of research evaluates the potential impacts of ICT on scientific collaboration before very large sums of money are spent on technology development and deployment. This type of evaluation increases in complexity when the technology is targeted for remote scientific collaborations that include a variety of scientists from different disciplines, institutions and countries. Current evaluation approaches include lab experiments that mirror current scientific practice (e.g., Sonnenwald, Whitton & Maglaughlin, 2003), socio-technical interaction network analysis (Kling, et al, 2003), and computer simulations (Nan, Johnston, Olson & Bos, 2005).

Intellectual Property (IP) and Other Legal Issues

Although it is outside the scope of this chapter to review intellectual property (IP) and legal issues in depth, it is important to recognize that IP rights and other legal issues impact collaboration. IP rights and their globalization are in flux and increasingly driven by private interests, including a merging of university-industry-government relationships linked to innovation and free trade (Sell, 2003; Etzkowitz & Leydesdorff, 2000). The Science Commons (http://www.sciencecommons.org) and the Creative Commons (http://www.creativecommons.org) are developing alternative, flexible copyright licenses for scientific publishing, licensing and data (Lessig, 2004; Nature, 2005.)

Issues concerning IP that may emerge from a collaboration and legal relationships among participants in a collaboration should be negotiated in the formulation stage to avoid misunderstandings and conflict later on after IP that appears to have market potential has been created or after liability issues have arisen (David & Spence, 2003; Lambert, 2003). Specific

[5] For example, one experiment, ATLAS, involving the Large Hadron Collider (LHC) at CERN is expected to generate 40 million megabytes of data per second, and need to archive and share among scientists worldwide one petabyte (one million gigabytes) of data per year when it comes online in 2007(CERN, 2005).

issues to be decided vary depending on the focus of the collaboration, and can include participants' claims to IP emerging from the collaboration, ownership and licensing of IP, dissemination of scientific data, and apportionment of liability with respect to violations of competition law, violations of human and animal subjects rights, and loss of reputation due to incompetent or unethical conduct competition (David & Spence, 2003; Reichman & Uhlir, 2003). Existing laws and formal policies regarding these issues vary across organizational and political entities, and new laws, interpretations of law and policies are in a state of flux (David & Spence, 2003; Reichman & Uhlir, 2003). For example, in Sweden university scientists are sole owners of IP they create even when their research is supported by university and government funding[6]. In comparison, in the U.S. the Bayh-Dole Act passed by the federal government in 1980 has encouraged universities to claim ownership rights and to commercialize results from government-funded research performed by their university faculty (Reichman & Uhlir, 2003). David and Spence (2003) and Reichman and Uhlir (2003) provide in-depth reviews of current laws and regulations.

Scientific practice is not only influenced by legal practices. Much of science follows informal traditions and norms, and in a collaboration these traditions and norms may vary among participants. For example, disciplines have different informal traditions regarding how IP is shared. Experimental biologists tend to be very secretive about their work and often patent their ideas, whereas mathematicians tend to be more open about their ideas (Walsh & Hong, 2003). This difference is reflected in these disciplines' formal publication policies and practices as well. *Science*, a leading journal for biologists and other natural scientists, does not allow pre-prints of articles to be distributed by authors, whereas math journals allow distribution of pre-prints (Walsh & Hong, 2003). Disciplines also have different perspectives regarding what constitutes IP. For example, when social scientists and computer scientists collaborate to develop new types of software applications or new functionality for a software application, who owns the copyright on the software? Computer scientists may consider themselves as sole owners because they developed the software algorithms and wrote the software code. Social scientists may want to share ownership because they view their original ideas for the software as a significant contribution.

Model agreements and contracts provided by funding agencies are emerging and the use of such models can reduce the time needed to develop a shared understanding regarding IP and other legal issues (Lambert, 2003; David & Spence, 2003). All participants, including students, should become aware of their rights and responsibilities. Without formal agreements, benefits from the scientific results may be claimed and/or liability denied by the strongest partner. For example, universities and businesses in advanced countries may claim all benefits from IP when collaborating with others in developing countries irrespective of the actual source of the IP (Oldham, 2005).

Sustainment Stage

After a collaboration is formulated and work begins, each collaboration needs to be sustained over some period of time in order for the collaboration to achieve its goals. Even with the best foundation and plans, numerous challenges can emerge during this stage. Research can be unpredictable and results may not be forthcoming (Latour, 1987; Atkinson, et al, 1998), or the

[6] However, businesses may ask Swedish scientists to sign over all rights to IP when they fund their research.

results may increase competition and secrecy among participants (Atkinson, et al, 1998). Challenges can be identified and addressed through an ongoing process of evaluation in which organizational structure and tasks, communication and learning are examined and evolve. Without such examination and evolution, a collaboration may fail (Olson & Zimmerman, in press).

Emergent Challenges
When a collaboration is not making progress towards its goals, it can be necessary to re-visit the organizational structure, management practices and goals (Shortliffe, Patel, Cimino, Barnett & Greens, 1998). Depending on the size of the collaboration and diversity of participants it may take up to a year to reach a shared, working understanding and effective organizational structure and management practices (Shortliffe, et al, 1998; Fisher & Ball, 2003). Even after an effective organization has emerged, collaborations may benefit from periodic reviews of the organization structure and practices. These reviews can be conducted by external stakeholders, including funding agencies and board of visitors, as well as informal and formal internal reviews (Sonnenwald, 2003c).

When scientists are not collocated, it can be helpful to have one person at each location designated as a site coordinator (Sonnenwald, 2003c). A site coordinator can handle location-specific administrative issues, ranging from reserving a videoconference room for weekly meetings to distributing allocated budget funds. This coordinator buffers local scientists from each individually having to deal with administrative issues related to the collaboration. In addition site coordinators can share information about local problems and jointly develop solutions.

Changes in administration and university or department policy may also have an unforeseen negative impact on a collaborative project. Understandings and agreements not in writing may disappear when personnel changes or other pressures emerge. When a department only has one scientist involved in a specific collaboration that work may be marginalized and discounted within the department because it has a small presence in the department (Cummings & Keisler, 2003). Because many university and department procedures and systems were designed for intra-departmental or intra-university collaboration, challenges with respect to inter-departmental and inter-university accounting and reporting procedures can be ongoing in this stage (Katz & Martin, 1997).

When resources were not distributed effectively in the formulation stage scientists may be unable to buy equipment or hire students necessary to complete research tasks in this stage. Even when resources have been initially well planned, funding agencies may not grant all monies requested and/or some participants discover they need additional funds. When this occurs there is a tendency to reduce travel among participants and reduce or even eliminate funding for scientists who are most isolated either in terms of geographic location or discipline (Cummings & Kiesler, 2003). Individual scientists may understand the need to reallocate funds but university administrators may be less tolerant of changes (Olson & Zimmerman, in press). In addition, there may be unexpected delays in getting equipment and materials, as well as visas for traveling to other locations due to changing international politics. Poor infrastructure, including unreliable electricity and phone lines as well as poor roads in developing countries, and a lack of knowledge and understanding about these and other local conditions can cause misunderstandings (Jones, Degu, Mangistu, Wondmikum, Sato & Kusel, 2004).

Scientists may also discover additional, unexpected differences. For example, they may come to realize they do not have shared norms with respect to students' participation (Cummings & Kiesler, 2003), or sharing information about the research with outsiders (Walsh & Maloney, 2002). As some scientists learn from each other during a collaboration, they may feel they need their partners less (Atkinson, et al, 1998). Ongoing challenges may also emerge from illnesses, deaths and family problems, honest disagreements regarding plans (Burroughs Welcome, 2004), and staff turnover (Jones, et al, 2004). In addition, some individuals may behave inappropriately, not honoring some aspect of the plan, not completing tasks, not sharing needed information, and not sharing credit appropriately.

Trust among scientists is an integral component of collaboration (Cl[illegible] Myers & Hoyt, 2002; Olson & Olson, 2000), and conflicting views of cooperation and competition may emerge during this stage (Atkinson, et al, 1998). There are different types of trust that influence how distrust among colleagues is managed. Cognitive trust focuses on judgments of competence and reliability, and affective trust focuses on interpersonal bonds among individuals. To manage situations where there is a high level of affective trust but a low level of cognitive trust, scientists may assign non-critical tasks to the person who is considered not cognitively trustworthy and establish controls to monitor task progress (Sonnenwald, 2003c). When there is a high level of cognitive trust and low level of affective trust, controls to monitor research activities and constraints on research activities may be established (Sonnenwald, 2003c). Trust is more easily developed among scientists within the same institution or within the same research team in multi-team, multi-institutional 'Big Science' projects than across institutions or research teams (Zucker, Brewer, Darby & Peng, 1995; Shrum, Chompalov & Genuth, 2001).

The size of a collaboration, geographic distances between participating scientists, task interdependency and competitiveness can exacerbate these challenges (Walsh & Mahoney, 2003). Challenges can make a collaboration stronger and more effective when they are handled constructively (Sonnenwald & Pierce, 2000; Stokols, Harvey, Gress, Fuqua & Phillips, 2005), with "an appropriate balance between diversity and debate among investigators on the one hand, and intellectual integration and social support on the other" (Stokols, et al, 2005, p. 212.)

Learning
Learning is an integral component of scientific collaboration, especially interdisciplinary collaboration (Klein, 1994; Maglaughin & Sonnenwald, 2005; Solomon, Boud, Leontis & Staron, 2001). In fact, collaboration is viewed as "one of the most effective forms of knowledge transfer" (Lambert, 2003, p. 38). Scientists need to learn from each other to develop a common working understanding regarding the research project, and how they can integrate their specialized knowledge to create new knowledge. Both explicit and tacit knowledge is exchanged among collaborators. Scientists may recognize this in the formulation stage (learning can be a motivation to initiate a collaboration) but it is in the sustainment stage that it may be most challenging. Unfortunately learning is not traditionally discussed or included in research proposals as a research activity (Davenport, 2005).

Learning requires time, reflexivity, disclosure, risk taking and trust (Solomon, et al, 2001). It takes time to teach and learn from others. As mentioned earlier disciplines and specialized areas of expertise have their own concepts, methods and languages, and there is a need to identify and understand these differences. Terms are used differently; the same term may have different meanings in different disciplines and different terms may have similar meanings. Collaboration with scientists in developing countries may face additional challenges with respect to learning. Research staff may need additional training, and after staff is trained they may leave the project for higher paying jobs (Oldham, 2005; Mervis & Normile, 1998; Bietz, Naidoo, & Olson, in press).

These challenges can be met when additional time and resources are allotted for learning. Specific strategies to facilitate learning include frequent and regularly scheduled presentations by students to all scientists working on a project (Sonnenwald, et al, 2002). Typically students are advised by one scientist, or at most two, in specialized areas of research. When students present the purpose of their research, recent research activities and results, and challenges they face, they are helping others learn about their and their advisor's specialized area. Another mechanism that facilitates learning includes scientists' own web pages that provide copies of their recent publications and pointers to other resources in their area of expertise (Maglaughlin, 2003). Drafts of publications, including proposals, project reports and research papers, can also be used to facilitate learning (Creamer, 2004). The drafts help identify differences among scientists' ideas which can lead to constructive discussions and learning.

Communication

Communication is another fundamental component of collaboration in this stage. Without ongoing communication tasks will not be coordinated, scientists will not learn from each other, research results will not be integrated, and perceptions of distrust may emerge. Projects that use more coordination and communication mechanisms have been found to be more successful (Cummings & Keisler, 2003).

It can be difficult to schedule meetings in geographically dispersed collaborations because time zones, national holidays, and organizational calendars differ. As discussed earlier the use of ICT, including e-mail, electronic calendars, audio conferences, video conferences and shared electronic boards, can facilitate communication across time and distances. However, for some tasks, such as brainstorming, face-to-face meetings appear to be most effective (Olson & Olson, 2000).

Stokols and colleagues (2005) found off-site retreats useful in reducing interdisciplinary tension and increasing intellectual integration. Project meetings can also be held in conjunction with national and international conferences. Some projects also have postdocs and graduate students learn techniques from scientists in other disciplines (Cummings & Kiesler, 2003). Other projects seek out individuals who understand scientific principles and practices found in the relevant disciplines, and can help resolve disciplinary differences and language barriers among the other scientists (Maglaughlin & Sonnenwald, 2005). Still other projects use video conferences in conjunction with electronic whiteboards to present and discuss group policy and practices (Sonnenwald,, et al, 2002).

It is important to revisit communication practices, including the use of ICT, periodically during a collaboration. Questionnaires, social network analysis, interviews and focused group discussions can help identify communication practices that are working well and which should be improved and ways they could be improved. Without effective formal and informal communication successful collaboration is not possible.

Conclusion Stage

In this final stage, successful results from the collaboration ideally emerge. It can happen that funding and other resources for the collaboration simply come to an end without results emerging. However, there can be different types of successful results, and dissemination and publication of results help others to learn from the collaboration.

Definitions of Success

An important result, of course, is the creation of new scientific knowledge, including new research questions and proposals as well as new theories and models (Stokol, et al, 2005). These are traditionally measured by publication and citation counts. Lee and Bozeman (2005) report that the total number of peer-reviewed journal publications for scientists in university research centers in the U.S. is significantly associated with the total number of the scientists' collaborations. However, when the number of publications is divided by the number of authors, this association disappears (Lee & Bozeman, 2005). Duque and colleagues (Duque, et al, 2005) also found that in the developing areas of Ghana, Kenya and the state of Kerala (India), collaboration was not associated with an increase in scientific publication. Thus there are open questions regarding how collaboration impacts publication counts.

Another traditional measure of success is citation counts. Numerous bibliometric studies have illustrated that coauthored papers in all disciplines investigated tend to be published in higher impact journals, cited more frequently and cited for longer periods of time[7] (Frenken, Hölzl & deVor, 2005; Leimu & Koricheva, 2005; Goldfinch, Dale & DeRouen, 2003; Persson, Glänzel & Danell, 2004; Glänzel, 2002). It appears that having an international coauthor can increase a paper's citation rate more so than having a national coauthor (Frenken at al, 2005.) Beaver (2004) proposes these results occur because coauthorship increases a paper's epistemic authority. Different types of knowledge are contributed by coauthors and there may be more rigorous review of papers within a collaboration, which increase the quality of papers that are coauthored (Beaver, 2004). Coauthors can also increase the visibility of a paper when they share information about the paper in conference and workshop presentations, discuss it informally with colleagues and distribute pre-prints to colleagues (Katz & Martin, 1997). This increased visibility may also lead to higher citation rates.

Other successful results may be less visible than publication and citations counts, but nonetheless important. These include career, educational, administrative, tool, business and socio-political

[7] However, there is evidence to suggest that citation rates of papers authored only by scientists within countries that are on the periphery of science is not greater than citation rates for single authored papers within those countries (Goldfinch, Dale & De Rouen, 2003).

developments (Cummings & Kiesler, 2003; De Cerreño & Keynan, 1998; Olson, Olson & Cooney, in press; Sonnenwald, 2003a). Scientists and staff may acquire new knowledge and skills during a collaboration that can lead to new career opportunities. This includes not only new scientific knowledge but also new knowledge regarding research methods, use of ICT and project management. Educational results include students who successfully complete their educational programs, and others who have been influenced by the project through outreach activities or as study participants. Educational results may also include the adoption of more effective teaching methods and practices that are shared among scientists across disciplines and distances or which emerge from innovative collaborative activities such as joint supervision of students across distances.

Administrative systems and practices may also be changed as a result of a collaboration. For example, when a collaboration is inter-institutional and/or international, it may require and help establish new ways of working with respect to the administration of grants and project accounting. Such changes within an institution may make it easier for subsequent collaborations and new forms of collaboration to be more easily established and sustained at that institution.

Innovative tools and improvements to existing tools may emerge from a collaboration. These tools may be scientific tools as well as project management, collaboration and other research support tools. Economic or business results may include patents, licenses, and/or new products and services that are used to form start-up companies or enable growth opportunities for existing companies.[8] When scientists from different cultures and countries collaborate, a successful outcome may also be an improved understanding among peoples from different countries and societies. In sum, there are many different types of contributions scientific collaborations make, and successful collaborations can be an inspiration to others (Olson, Olson & Cooney, in press).

Dissemination of Results

Dissemination of research results is an important component of all scientific research. A traditional method of disseminating results of a collaboration is through co-writing presentations and publications. Scientists most value coauthors who show consideration (e.g., exercise tact when criticizing ideas, show appreciation for other's contributions, and are willing to go beyond one's formal commitment as coauthor) and who are dependable (e.g., keep commitments, keep others informed about a manuscript's status and changes, and complete writing tasks in a timely fashion.) (Bozeman, Street & Fiorito, 1999).

When the collaboration is interdisciplinary, a challenge may emerge regarding the selection of publication forum (Maglaughlin, 2003). It may be challenging to find an appropriate forum to publish interdisciplinary results that do not clearly belong to one discipline or another. In some areas, new interdisciplinary journals (e.g., the *Journal of Biomedical Discovery and Collaboration,* http://www.j-biomed-discovery.com/) are emerging to help address this challenge. In addition, scientists from different disciplines may value publications differently. For example, typically computer scientists highly regard publication of a paper at an ACM conference where acceptance rates may range from 15 to 25%. However, in other fields such as business and psychology, there are conferences with 75-100% acceptance rates and publication at those conferences is not so highly regarded. Furthermore, disciplines have different

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[8] These results may, of course, also emerge from single investigator research.

expectations with respect to paper content and publication speed. In social science papers can be 20 to 30 pages in length, and take 2 years from time of submission to time of publication. In chemistry, papers may be 2 to 10 pages in length and be published within 3 months of submission. Problems can emerge when scientists do not know about these differences and fail to discuss the rationale behind their suggestions regarding where and what to publish.

Reaching consensus regarding authorship inclusion and order may also be challenging, and these difficulties increase as competition increases (Atkinson, et al, 1998). Who among the students, lab technicians and co-principal investigators should be included as an author? What constitutes a significant contribution meriting co-authorship versus inclusion in the acknowledgments section of a paper? When should authors cite their collaborators' papers? It is recommended that these issues are best discussed when there is a sense of what the research results are and before papers are written (Burroughs Welcome, 2004).

Disciplines have different expectations about the meaning conveyed in authorship order. For example, library and information science typically assumes authorship order is linked to level of contribution, with descending order indicating descending contribution. Biology assumes the first author is the student or junior scientist who did the bench or lab work and the last author is the principal investigator who developed the initial idea and/or procured the funding necessary for the research. Tenure and promotion committees as well as colleagues may not take into account disciplinary differences with respect to publication forums and authorship order when evaluating a scientist's contributions.

There is a danger of honorary co-authorship where authors are included for political reasons, such as to help increase the acceptance of the work (Cronin, 2001, 2005). Questions of content responsibility and erasure of style also arise (Cronin, 2001). With large numbers of authors, who is responsible for a paper's content? Whose writing style dominants or whose voice is heard? Cronin (2001, 2005) uses the term, hyperauthorship, to refer to those papers which include massive numbers of authors. For example, the high energy physics and biomedical research communities are proposing that co-authors' contributions be identified on each paper similar to the way movie credits are handled today. Some journals, such as the *Journal of the American Medical Association* (*JAMA*) have established criteria for authorship, require one or two authors to assume responsibility for the work's integrity, and require all authors to identify their contributions to the work (see http://jama.ama-assn.org/ifora_current.dtl for details). Collaborations may also create their own policy regarding co-authorship. For example, the Laser Interferometer Gravitational Wave Observatory (LIGO) has created a publication policy that outlines co-authorship requirements and publication review procedures that its members must follow. The policy can be found at http://www.ligo.org/T010168-02.pdf.

Conclusion

The factors which impact scientific collaboration, as reported in the literature and presented in this chapter, are summarized in Table 1. A factor first emerges as important during a specific stage of collaboration, yet its importance may not necessarily diminish in subsequent. However, as one would hope, the number of new factors emerging decreases as a collaboration progresses through stages.

Table 1. Emergence of factors during the scientific collaboration process

	Stages of Scientific Collaboration			
	Foundation	**Formulation**	**Sustainment**	**Conclusion**
Factors	Scientific	Research vision, goals & tasks	Emergent challenges	Definitions of success
	Political	Leadership & organizational structure	Learning	Dissemination of results
	Socio-economic	Information & communications technology	Communication	
	Resource accessibility	Intellectual property & other legal issues		
	Social networks & personal			

Some of these factors also emerge in single-investigator scientific research, yet in single investigator research the factors may be less complex and easier to address. For example, IP can be easier to handle when there is only one inventor in one organization. However, some of these factors do not emerge in single-investigator research. For example, publication issues, such as co-authorship order and selection of publication forum, is not something that needs to be negotiated in single-investigator work.

Scientists and organizations should consider the benefits and costs of collaboration before deciding to collaborate. Collaboration only for the sake of collaboration does not seem warranted given the number of factors that should be taken into account before and during a collaboration. Furthermore, as the number and diversity of participants and the complexity and uncertainty of the scientific work increase, so does the complexity of the factors. The negative consequences from not addressing the factors may also increase. There is a real need to consider these factors and the effort and other costs required to manage them before beginning a collaboration. However, when collaboration can provide new possibilities, it is well worth the effort. New possibilities offered by collaboration can be many and diverse, including new ways of conducting science and new knowledge to the benefit of many.

Although there has been an increase in research on scientific collaboration during the past decade, many challenges remain. Important research questions to consider include the following: How do gender and cultural issues impact scientific collaboration, both in the selection of collaborators and the process of collaboration? How can scientists from different disciplines most effectively develop a working understanding? How does trust emerge and how can it be sustained across distances, cultures, disciplines and institutions? What methods can be used to evaluate the impact emerging ICT may have on scientific collaboration, and to influence ICT development, before large sums of money and time are spent on its development and deployment? How should intellectual property rights and other legal issues evolve to support collaboration across disciplines, institutions and countries? How can we best capture and reward multiple, diverse outcomes of scientific collaboration given today's systems and institutions?

Scientific collaboration continues to increase in importance because it can uniquely address complex, critical problems. As complex, critical problems continue to emerge and introduce new goals for science, and as the contexts in which science takes place continue to evolve, new collaboration challenges will emerge. New collaboration strategies will be needed. The need to discover new strategies and to address the many, currently unanswered questions illustrates the necessity and importance of continuing and expanding research on scientific collaboration.

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