Science Communication Today

SCI White Paper | NATIONAL SCIENCE COMMUNICATION INSTITUTE

SUMMARY

Nearly every aspect of our lives today is infused with science and technology — from health care to finance to entertainment, from the food we eat to the books we read, the cars we drive, and the homes that keep us safe and warm. And the need for more science is obvious. Where are the solutions we demand to illness, pollution, hunger, transportation, and more? Yet against this backdrop of high achievement and even higher expectations, the American public's faith in science has been declining for years. Science itself is not entirely blameless for this decline. As an institution it hasn't kept pace with the needs and expectations of society to do a better job of communicating. Part of the reason for this seeming indifference is simply institutional momentum. Part is also due to a lack of leadership on this issue. Many scientists and their organizations know a communications problem exists but there hasn't been any organized guidance yet on how to improve the overall communication culture in science, nor is there general acceptance among the foundations and agencies who fund science that better communication is something that needs funding. More investigation of this issue is needed, as well as evidence of the benefits of change.

The current culture of science communication in America is defined and supported by four major pillars: journal publishing, institutional capacity, secrecy and recognition. This structure isn't necessarily onerous; rather, understanding it is critical to understanding what avenues might be open for improving science communication in the future. What are the impacts of the current communication deficit in science? In general they can be grouped into three categories: restricted access, lost opportunities, and a lack of civic engagement. Awareness of the communication problem in science is growing today but only in specific areas and only in fits and starts. There isn't widespread acceptance yet of the right role of communication in science, nor is there widespread recognition yet that science communication is a unique discipline as discussed in the introduction to this paper. nSCI's role is to help raise awareness of both the science communication field and the communications deficit in science, define the challenges ahead, facilitate conversations on solutions, and provide assistance to test the utility of new approaches. In all, nSCI has identified eight areas of science that rely heavily on effective communication and that can be targeted with improved communications. These areas are divided into two groups—those that involve science discovery tools and dynamics and those that involve improving science understanding. nSCI's "discovery" focus areas include research collaboration, informatics, study design, and tech transfer; "understanding" areas include science writing, STEM education, science marketing and public policy. nSCI believes that science needs better communication tools and practices in these areas to help realize the full potential of research and also make faster advances in science education, science policy and other areas where science and society intersect.

All of these better communication tools and practices won't simply unfold overnight, though, nor will their eventual impacts: scientists and their institutions will first need to agree on the need for change, and then work together to find the best solutions and remain patient and diligent. The thoughtful work and attention that many individuals and organizations have contributed to the cause of improving science communication has been helpful, but a concerted and focused effort like that being proposed by nSCI is now needed to create organized, timely and sustainable change.

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INTRODUCTION

This report is the first draft of a first attempt to define the field of science communication, the need for better science communication, and the role that this paper's sponsor— the National Science Communication Institute (nSCI) — hopes to play in improving science communication. To what end? Assuming the need exists, what is the goal of improving science communication? nSCI and others believe that improved communication will lead, perhaps rapidly, to measurable improvements both in science discovery and the public understanding of science.

First, exactly what is science communication? It doesn't exist yet, at least not as a unified and comprehensive field. Parts of it do. Science writing is well-defined, for instance, and some organizations treat the art of presenting science as science communication. But nSCI considers science communication to be the common denominator that unifies many of the disciplines already supporting science with their own distinct structures and constituencies. STEM education is its own field, for instance, but it requires the tools and training of effective science communication to conduct successfully. The same is true of tech transfer, informatics, and study design. Science marketing isn't a field at all but it should be — it's a very practiced specialty that applies the knowledge of marketing within the unique culture of science.

In all, nSCI has identified eight areas of science that rely heavily on effective communication. Broadly defined, these areas are divided into two groups — those that involve science discovery tools and dynamics (how science communicates between scientists, for instance), and those that involve improving science understanding. nSCI's "discovery" focus areas currently include research collaboration, informatics, study design and tech transfer, and nSCI's "understanding" focus areas include science writing, STEM education, science marketing and public policy. There is some crossover, of course. Effective science writing, informatics and marketing are all important to both discovery and understanding, but this is the general conceptual model.

The communications expertise needed to succeed in these eight areas (and perhaps others which will become apparent in the future) all flow from a common base of science communications knowledge, training and experience. It therefore stands to reason that treating science communication as a field unto itself is the best way to ensure communications consistency, efficiency, effectiveness, and success across these eight areas of science — that it makes more sense to recognize science communication as a field with a wide range of applications than to treat this wide range of applications as completely disparate but with significant communication components. Consider math and computer science, for instance. These are also clearly common denominators in science with a very wide variety of research applications, but what if they weren't independent disciplines? Could the knowledge, training and experience of math and computer science possibly be cobbled together by scientists on as needed on ad hoc basis? The answer is clearly no. Math and computer science can't be afterthoughts, and neither can communications.

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This appreciation for the role of communications is something that every public-facing enterprise has long understood. In big businesses, for instance, a communications office (or sometimes a marketing office, external relations office or something similar) oversees the public face of that enterprise — what the organization says, how they say it and to whom, what sort of image the organization projects, and so on. This communication office often oversees press relations, investor relations, marketing, reporting and more, and can also work closely with or oversee the information technology office. Centralized, expert communications support is an established, essential resource for ensuring that an organization's messages are clear, that it has a unified voice, and that it does an effective and efficient job of reaching out to both internal and external audiences in a persuasive way, whatever the objective of that outreach may be — education, charity, sales, or, scientific research.

Science doesn't normally utilize this kind of organizational structure, though. The communications offices of larger research institutions usually don't focus on research-level communications, but on higher-level organizational communications matters instead. Also, scientists — who are most often limited in what they spend and how they spend it by the government, sponsor, and foundation grants they receive — haven't had the budgets to create the in-house expertise to focus on research communications and marketing. But now that science is increasingly called upon to be a public-facing enterprise like business — responding to the need for increased efficiencies and more effective messaging — science should look hard at making an organizational, structural change. There's a reason Fortune 500 companies spend billions and billions of dollars every year on services like marketing, marketing communications, advertising, public relations, investor relations, and government relations: because they're essential.

The none-too-subtle argument here is that science should also treat communications as an essential discipline, integrate science communication more effectively into the culture of science and the framework of research and research institutions, and make better use of what this new and improved communications presence can offer. Understanding this argument is a necessary first step to understanding the following descriptions of the problems and possible solutions in science communication today.

What are the key components of successful science communication? Effective writing, marketing and public relations top the list — but with a unique ability to translate technical materials for lay audiences in an accurate, understandable, and sometimes a persuasive way. This means that science communication isn't necessarily the same as technical communication. The two share many of the same skills, but their audiences are typically different so their thresholds for acceptable complexity are different as well. Technical writers usually write for industry and others for whom reading level and subject familiarity isn't an issue, while science communicators need the ability to communicate clearly, persuasively, and accurately about technical matters for a variety of audiences — not just other scientists, but for the general public and policymakers — and also know how to use tools that help share knowledge and promote understanding. More about the structure of effective science communication will be discussed in a future nSCI White Paper.

THE CURRENT PROBLEM

We live in a world today where the contribution made by science is truly staggering and the need for more science is equally pressing. And yet the American public's faith in science has been declining for years. Why? Social psychologists might be able to explain away some of this decline. Political discourse might be able to account for more. But science itself is not entirely blameless. Here at the dawn of what history will someday refer to as the Information Age, science as an institution hasn't kept pace with the needs and expectations of society to do a better job of communicating. Part of the reason for this is institutional momentum — of both science itself and the many organizations and networks that create science. Part is also a lack of leadership on this issue. Many scientists and their organizations know the problem exists, but there isn't any organized guidance yet on how to improve the overall communication culture in science, nor is there acceptance among the foundations and agencies who fund science that better communication is something that needs to be funded.

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So what exactly is the current communication problem in science? Let's do an alternate reality exercise. Suppose you live in a world where there aren't any cookbooks. The prevailing wisdom is that cookbooks aren't necessary because only chefs cook and the language of cooking is too arcane for most people to interpret. To become a chef you need to study lots of math, and then you get promoted based in part on the number of recipes you publish in culinary journals. These journals own the copyright to the recipes they publish, which is another reason why they can't appear in cookbooks, even in "dumbed down" fashion. The state of collaboration between chefs is a little better than with the public. They hold conferences and peer review each others' recipes, but chefs specializing in different culinary styles never really interact. Everyone makes main courses and desserts but there isn't a lot of interdisciplinary sharing of cooking techniques, equipment, recipes, best practices, and so on.

This analogy isn't intended as an affront to chefs, scientists, or your ability to understand a complicated issue. Rather, the point here is to illustrate the rather absurd nature of some of the communication gaps in the current relationship between science and itself, and science and the general public. Scattered between these gaps are the outcomes that interdisciplinary collaboration is lacking, data sharing is hampered by concerns over secrecy, communication best practices and resources aren't available or integrated into the foundations of research projects, the general public and policymakers who listen to the general public are too often misinformed about science (which can trace back to bad communications), science education isn't utilizing the communication tools and techniques that resonate with today's kids, more science isn't spinning out of academic institutions because it isn't being packaged properly for investment audiences, and more.

And what if anything do these outcomes have in common? In this paper we suggest that science communication is perhaps the single most important common issue, and that improving the current culture of communication in science can lead to widespread benefits both for science and the public. In this paper we will first examine this communication culture and then take a look at the discovery and understanding areas of science communication where reform efforts should be focused: on the discovery side, science collaboration, study design, informatics, and tech transfer, and on the understanding side, science writing, marketing, STEM education and public policy.

First of all, the current culture of science communication in America is defined and supported by four major pillars: journal publishing, institutional capacity, secrecy, and recognition. These pillars also define the way that science communication has operated in the past. This structure is not necessarily onerous (though some have characterized it as such); rather, understanding this structure is critical to understanding what avenues might be open for improving science communication in the future.

PILLAR 1: JOURNAL PUBLISHING

The current practice of journal publishing is the most familiar straw man to be stood up in this debate — perhaps undeservedly so because journals have played an enormously positive role in science and will continue to do so. In the traditional model of journal publishing, scientists submit papers to select journals in their field and these papers are anonymously reviewed by peers (other nontraditional models also exist, and their popularity is growing, as will be discussed later on in this paper, but the traditional model is still dominant). Then, a select few papers get accepted, edited, and published — perhaps the most "mainstream" papers, critics might allege, or the papers that conform with the current body knowledge, but in any event the papers that peers have judged to be the most worthy. Having an article accepted for publication in a prestigious journal can be very beneficial for up-and-coming assistant professors because establishing a strong record of successful publishing is one of the most important factors in whether they will be offered tenure — a lifetime position at their university. However, this "publish or perish" emphasis in tenure decisions has likely exacerbated the importance of journals in science communication. Readership of these painstakingly-produced (and often heavily financed) articles can often be counted in the mere hundreds, and the impact of this work (whether measured through citations or other indices) can be far less than desired. Journal publishing also comes under fire for its impact on information access:

- Most subscriptions are very expensive, which coupled with tight budgets means that fewer libraries can afford them. Some have also questioned whether it is fair for the public to fund research and then pay to access the findings.
- Journals typically own the copyright to the final peer-reviewed and formatted versions of published articles, meaning that the research details they contain cannot be widely distributed or shared beyond immediate "know colleague" peer groups, even for free (sometimes for a year or so, sometimes in perpetuity), that nonsubscription access to this research can be restricted for years, and that information releases are usually delayed by publishers (see Elsevier 2011 for more details on the copyright policies of Elsevier, the world's largest journal publisher). This latter practice of delaying release, called embargo, is intended to serve as a marketing tool to stage the release of new articles to journalists in a predictable manner and thereby increase the PR value of these articles (since news agencies can say this research is brand new and just being released).
- Articles are written for experts in the field and not for public consumption, and sometimes can't event be understood by other scientists working in the same field let alone by scientists working in other fields.
- The journal publishing industry is very concentrated. The largest three publishers — Elsevier, Springer and Wiley, who have bought up many of their competitors — now publish 42% of journal articles (McGuigan 2008), and
- From a societal standpoint, for a generation where easy and effective communication is a centerpiece of daily life, journals can feel like anachronisms and actual barriers to effective communication.

The issue of journal publishing and its role in science communication will be explored more fully in a future nSCI White Paper.

PILLAR 2: INSTITUTIONAL CAPACITY

Despite its visibility, journal publishing isn't the only issue in science communication today. Communications capacity is generally an afterthought in science. Engaging communities, building partnerships with other institutions and with industry, sharing information with other researchers and with the lay public, using the latest informatics tools to evaluate data, and educating policymakers on relevant findings is done more often than not on an as-available and ad hoc basis. You won't find professional PR firms running the communications operations of most research institutions because these institutions (and their funders) rarely see the need and therefore haven't provided the budget. Science as a field (although there are notable exceptions to this generalization) hasn't yet seen the need to focus on communication and fund it accordingly, so effective science communication and collaboration have generally been grossly undermanned and underfunded as a result. Building institutional capacity and offering assistance where there is none is where most of nSCI's work will be focused, as discussed later in this paper.

PILLAR 3: SECRECY

Science has also been accused of being insular, and this isolation has been cited as the reason for a lack of adequate communication. However, there are legitimate reasons for this dynamic and the extent to which it occurs differs from one research area and institution to the next (Velden 2011). For instance, new knowledge needs to be protected until it can be published, patented, or otherwise capitalized upon. Trade secrets might also be important: When academic chemists work on industry-funded research projects, for instance, they have to accept a certain trade-offs with regard to protecting industry secrets (Laszlo 2006). This situation is not new, and it is not unique to science.

PILLAR 4: RECOGNITION

The need for individual recognition is fundamental to the current state of science communication. Recognition might flow from journal publishing (pillar 1), or discovery (made possible by pillar 3), and is even sometimes related to good PR efforts or science that captures the public's attention (pillar 2). Overall, though, recognition is how scientists survive the tenure system, how their work gains credence with their peers, how it gains currency with policymakers, how it gets capitalized upon by publishers, and more. Scientists need to be recognized for their work and their expertise, and any change in communications protocols that unfairly biases the current system in favor of those with the best PR staff will never be accepted by science, nor should it be.

So in summary, science prefers to communicate through journals, there isn't enough money, interest, or institutional buy-in yet to make wholesale changes in how science communicates, and even if and when this happens, there will still be a need for a certain amount of secrecy and a need to maintain the meritocracy system of recognition. These are the fundamentals from which additional change will need to flow. nSCI's focus on improving science writing, marketing, informatics, study design and data sharing, STEM education, science policy and tech transfer all works within — or at least will be contemporaneous with changes in — how these three pillars are structured, particularly capacity.

It is also important to note that when many who care about science communication talk about strategies for reform, they often address only part of the challenge: how can science teachers teach better, how can scientists communicate more clearly, and how can policymakers understand issues better? This is fine, of course: specialization is important, and grants and donations are easier to come by for discreet causes like improving STEM education. However, the most complete, long-lasting and impactful solutions to these questions are deep and interrelated and involve rethinking our approach to science communication from the ground up.

What are the current challenges in science communication in the areas where nSCI is focusing? The shaded areas of the next two pages offer an overview.

"DISCOVERY" FOCUS AREAS

SCIENCE COLLABORATION: Advanced collaboration between scientists trained in several different fields has become essential in many areas of scientific research. Interdependence, joint ownership and collective responsibility for data and data analysis is needed among many modern research teams, even those housed in the same wing of the same institution. In the face of this need there are well-established challenges to collaboration: distance, common interests, common goals, incentives, trust, organizational and legal barriers and more. Some research teams have met theses challenges and are far ahead of the collaboration curve; others lag far behind. In general, there's a lot of room for improvement. Databases that share research findings in a timely and usable fashion are not common and research collaboration tools and best practice guidelines are still novel.

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SCIENCE INFORMATICS: Informatics is a budding and crucial field. For now, almost every institution and area of scientific research defines informatics somewhat differently but the primary focus is always on technology — how computers can help us discover more. Some of the specific challenges currently being tackled by informatics includes integrating widely differing data formats in research datasets, standardizing data formats for future research collaboration efforts, identifying and pulling more data into depositories and architecting designs for data storage, retrieval and use, and developing new tools that can help analyze and sift through increasingly unmanageable volumes of "big data." Despite the current attention being paid to these technology-centered challenges, there also needs to be more focus on big picture efforts. Informatics isn't just about computer systems, but about our human ability to peer into research and make insights and connections and integrate new and helpful perspectives — in short, to do a better job of communicating. Flooding more advanced computer systems with more data will no doubt lead to remarkable breakthroughs, but being able to intuit patterns, applications, and trends by integrating and comparing the right sets of data, as well as sharing tools and best practices between disciplines could, on the other hand, lead to grand new applications, solutions, and discoveries.

SCIENCE DESIGN: Research study design is one of the most well-developed areas of science. Legions of experts have compiled and refined years of best practice guidelines on the proper design, conduct and analysis of research studies, covering everything from human subject protection to statistical methods. However, as the expectations of our information society continue to evolve at breakneck speed, holes have developed in best practice frameworks. Communication is one such shortcoming. Many studies with potentially far-reaching impact still allocate only a nominal budget for sharing findings and communicating these findings to the public — even the bare essentials like building a good website for the study, keeping it current, preparing policy briefs and press releases, and making important connections with other researchers in the field through social media, email, and other direct outreach (to the credit of researchers, conferences are also widely used as communication tools but these are not adequate by themselves to reach beyond peer communities). Other studies might have ambitious enrollment plans for potentially life-saving treatments but an inadequate budget for participant recruitment and enrollment, and no on-staff expertise for writing and designing compelling outreach materials. Databases are another shortcoming of modern research studies. Like communication components, data collection and analysis isn't usually designed with sharing in mind. Data is kept under lock and key until journal articles are published, and comparison with other research datasets is rarely a consideration, let alone a practical objective. Study selection itself is a third shortcoming — the issue of whether many research studies are even necessary. Publish or perish pressures may be producing a glut of studies that didn't need to be done in the first place or that should have been done better. In summary, designing studies with better communication and data components, increasing collaboration, and reducing the pressure to publish studies will all help improve current research study designs.

SCIENCE TRANSFER: "Technology Transfer," as the term is normally used, usually encompasses issues focused on acquiring and licensing patents. It's an important focus of many higher education institutions who see more effective tech transfer programs (rightly or wrongly) as a potential economic engines for their universities and local economies. Some tech transfer organizations have had more success than others. The most recent survey conducted by the Association of University Technology Managers (AUTM), indicates that 11 of its roughly 200 member universities accounted for more than half of all the licensing and royalty revenues generated from university patents in 2010 (Wylie 2011). In addition, only 16% of tech transfer offices retained enough of the generated revenue to cover their ongoing costs, meaning that the vast majority of these offices run at a perpetual deficit. This lack of adequate funding is one reason why some tech transfer offices are more successful than others. Another reason is institutional capacity for communication-related functions: successful offices add value to ideas and have business, marketing, and communications expertise in-house or on-call to develop promising ideas and shepherd them into the marketplace. Yet another reason is communication itself: involved transfer processes like in pharmaceutics requires keen attention to communication processes — between technical teams, teams and regulators, different organizations, and more. Focus is another issue that could be improved. Tech transfer doesn't need to single out only on patentable technology; with adequate investment and staffing it can and should also focus more on science (Microsoft 2006).

"UNDERSTANDING" FOCUS AREAS

SCIENCE MARKETING: Marketing is a key component in the success of every public facing enterprise. In science, marketing simply means communicating science clearly and effectively for the benefit of both science and the general public. What are some of the situations where this applies? There are both internal and external applications of better marketing, some which overlap. Internally, the old adage about how the world will beat a path to your door if you invent a better mousetrap is unfortunately false. It always has been, but in the meritocracy of science this adage just seems like it should be true. Better communication tools mean more effective, timely, and cross-disciplinary collaboration, which might pave the road to more discovery. At the crossroads, better marketing is also useful for more mundane but essential goals like reporting to donors and raising more funds for research. Externally, better communication is critical for everything from educating and influencing policymakers to spinning successful tech transfer initiatives, enrolling participants in studies, getting kids interested in science, and more. There is much room for improvement in the current model of science marketing, and this improvement is rooted in improving the institutional resources, capacity and budgets for this kind of work, which will first require proving the cost, impact, and efficiency benefits of this approach.

SCIENCE WRITING: Effective science writing underscores everything in science communication. Unfortunately, writing is a field where everyone feels they're an expert, and changing an information "owner" culture like science into an editorial culture as is normal in any public-facing enterprise (where specialists are ultimately responsible for crafting messages for specific goals and customer groups) can be very difficult. In academia, which considers its primary customers to be other scientists, writing is directed mostly toward journals. Access issues aside, this peer-to-peer writing is often so dense that it becomes unintelligible, even to other scientists. Improving access to more journal articles in more disciplines is a worthy goal but understanding these articles can require a translator, not only because of the subject complexity but also because of the inaccessible writing style that has become the lingua franca of science journals. As science writing ventures into journalism there is often a lack of understanding between scientists and journalists about what constitutes effective writing — finding the right and necessary balance between clarity and accuracy. And when science writing attempts to bypass journalists and go directly to the public, scientists and their institutions rarely have the in-house expertise to do an adequate job of communicating (Tanona 2011). Explanations for this dynamic vary, but the communication field's lack of standing in research science may bear most of the blame as well as most of the potential for reform.

SCIENCE POLICY: Science policy in America is at the core of just about everything — water, energy, health, agriculture, conservation, climate, defense, and more. And of course, many of these issues are also linked and have multiple implications at local, regional, national and global levels. Therefore, given the importance of good science policy it's critical to our futures to reverse the trend in America of politicizing science policy. It is no longer possible to formulate policies for the public good by drawing on a single set of scientific facts. Every camp has their own "experts" and "facts" and the public is left to choose sides. This is an outgrowth of our information society, but it is also an outgrowth of poor science communication. Creating science policy in America that is more responsive to science begins with improving the communications infrastructure of science. Sound science is necessary for informed policy-making but it is not by itself sufficient. Policy recommendations also need to include storylines and plausible options developed through collaboration with a wide range of stakeholders. And these new policy options aren't the better mouse trap to which customers will naturally flock. Options need to be presented in ways that reach their audiences, and options need to effectively rebut the science nonsense that can flourish in our sound-bite culture. Establishing more cross-cutting foundations for science policy is also important — active collaborations between research institutions, corporations, infrastructure providers (transportation, energy, etc.), STEM education, and more.

SCIENCE EDUCATION: We've all heard the sobering news about STEM (science, technology, engineering and math) education: there aren't enough qualified STEM teachers in our K-12 systems, most high school students graduate without an adequate background in math and science, and students who choose to study math, science and engineering in college have very high rates of attrition compared to other majors (CRS 2008, National Science Board 2012) — meaning that most switch majors or don't finish their degrees at all. nSCI believes that better science communication can help repair this situation — in schools, in the public sphere, in the public policy arena, and more. Science education doesn't start in the classroom, after all, but with kids getting excited about science, and science policy works better if the public understands and is inspired by science and discovery. Building and maintaining this excitement and inspiration is slow pitch softball for marketers: making textbooks more entertaining, making sure teachers are properly trained and educated and have the right kinds of support, making sure that science education has a strong hands-on component, and making sure that Congress follows through on its frequent promises to markedly increase funding for STEM education (commitments that have recently been picked up by private industry due to the increasingly urgent need for a more STEM-literate domestic workforce). STEM reform efforts also need to focus internally, however: is there a more fundamental reason why kids don't or can't follow through with science that's not related to homework, teachers and funding? Examining the way science is communicated to students will help, as well as examining the role, necessity, and impact of math education requirements and methods in science education since math education is clearly the weakest link in college-level science education. This issue will be explored in detail in a future nSCI White Paper.

CALCULATING THE IMPACTS

What are the impacts of this communication deficit in science? Many have already been outlined in the previous section. In general these impacts can be grouped into three categories: restricted access, lost opportunities, and a lack of civic engagement.

RESTRICTED ACCESS

A lack of access to science information is the core problem in science communication today. Improving access will improve science, and public engagement in science. Access issues run the gamut from journals to writing styles to database interoperability issues:

- "PILLAR" ISSUES—JOURNALS, INSTITUTIONAL CAPACITY, SECRECY AND RECOGNITION: Most academic journals are not "open access" (OA for short), which means the information they publish is owned by the publisher and is only accessible only via subscription. While OA repositories are on the rise they aren't the norm, so most peer-reviewed journal articles aren't freely and publicly available (until the journal's copyright expires), versions of these article that substantially duplicate content can't be widely circulated, and pre-print versions can only be used for limited academic purposes. There are exceptions to these restrictions, and authors can sometimes pay for additional rights, but this description is generally correct. So, for instance, suppose a researcher publishes a journal article announcing her discovery of the unified field theory, and then wants to write a book describing this information in lay terms. She can't because for-profit or widespread circulation of her work to anyone other than her "know colleagues" is prohibited by the publishers (for more details on journal copyright policy, see the Project Sherpa website listed in the "additional reading" section of this paper's reference section; also see Elsevier 2011). This throttle on information flow is normal in the publishing world and a normal part of protecting intellectual property in any situation. However, academic journals—perhaps much like pharmaceutical companies developing vaccines for HIV/AIDS or Malaria — occupy a precarious intersection between free

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commerce and the public good, and the for-profit model doesn't always work well under these circumstances. Subscription costs are a related concern about journal publishing. In the past, libraries and research institutions have been charged (literally) with the responsibility of making sure this information is available. However, in recent years, journal prices, which are already high to begin with — often more than $1,000/year — have risen at well above the rate of inflation (four to five percent) against the backdrop of decreased funding for libraries across the country. As a result, between 2009 and 2010, data from the Association of Research Libraries (ARL) showed a slight decrease in average expenditures for academic journal subscriptions, meaning that many subscriptions were cancelled — 34 percent of libraries (mostly academic) in 2011 cut subscriptions, and 44 percent planned to do so in 2012 (Bosch 2011).

Bad publicity (and other issues related to a lack of institutional capacity for science communication) and secrecy have also played a major role in reducing access to science information. How many science studies have gone completely unnoticed over the years simply because they became buried in an obscure journal or perhaps never made it into a journal but got left on the dissertation shelf of their university library or locked into the database of their industry sponsor? It's impossible to calculate the loss to science due to lack of access, but going forward, better visibility and sharing are certainly possible, and with this visibility and sharing will come more benefits.

Breaking down the barriers posed by science communication pillars should not be limited to journals, either. There is also a lot of brilliant work that goes unnoticed by science because it shows up in the wrong venue — in a book or a magazine article instead of a journal article, for instance. Science doesn't have a magic ball that sees all. It still takes a deliberate effort to track and integrate information, even in today's world of seemingly effortless information access.

- NSCI FOCUS AREA ISSUES: A lack of access and a resulting lack of opportunity results from the challenges described in the previous section. Subscription issues aside, for instance, journal articles are most often written in a style of English that is nearly impossible to decipher by anyone outside a particular area of expertise (and even experts can have a hard time understanding journal articles). And math and science textbooks often suffer from the same approach. There's a general rule that Institutional Review Boards use when evaluating whether very complicated medical consent forms can be understood, and this rule is that public-facing science materials need be written at an eighth grade level and no higher. What does this mean? Are college students and scientists incapable of understanding college-level writing? No. But until students get into graduate school and are firmly entrenched in the communication style of a particular field, the biggest barriers to understanding might be the way information is communicated and not necessarily the information itself. The same can be said for making interdisciplinary learning more accessible. Databases are another area where access can be improved — within studies, within fields, and between fields. Efforts to improve collaboration will yield some improvement in this area, as will advancements in informatics. For now, datasets are rarely shared, and even more rarely integrated (which requires understanding all of the assumptions, notations, abbreviations, calculations, and other issues involved). Proprietary data is locked up in study sponsor databases for future commercial use or perhaps to protect participant privacy, and lots of data never gets mentioned at all, particularly for unsuccessful studies. Making data

> … the biggest barriers to understanding might be the way information is communicated and not necessarily the information itself.

access easier — perhaps even universal — will require a hugely collaborative effort and agreement in science, but the result could be mark one of the most important advances in scientific research in our lifetimes.

LOST OPPORTUNITIES

Lost research dollars, delayed opportunities, missed discoveries affecting science and health, misdirected policies, environmental damage — the list goes on. We can only speculate about the total value and impact of lost opportunities in STEM education, public policy, and collaboration, but clearly there have been impacts. The impacts of some of these lost opportunities are measurable, though. For instance:

- In cancer research, a recent report by New York's Mount Sinai Hospital (Sinai 2011) concluded that over 90 percent of all clinical trials are delayed in large part because of difficulty with patient enrollment — a specialty that nSCI considers to be part of science marketing. In addition, about 20 percent of principal investigators fail to enroll even one patient, another 30 percent fail to meet their overall goals for patient enrollment, and 40 percent of cancer trials funded by NIH are never completed or published. Of course, not all of this patient enrollment shortfall is due to poor marketing, but some of it may be; as people who review lots of research studies realize, there are no widespread best practice guidelines for how to enroll participants online, how to effectively reach out to your community for participants, and so on. Study marketing is often a seat-of-the-pants effort where project managers pull double-duty as marketing managers and with very little or no marketing experience or budget.
- Tech transfer has been an important policy initiative for the past several decades but its success is very uneven across institutions and it could accomplish more. In their zeal to capitalize on the work of professors, many tech transfer systems end up doing just the opposite, instead creating underfunded systems that patent ideas and then leave them in the dustbin while simultaneously preventing professors from writing about their research in journals (since the tech transfer process transfers the copyright out of the hands of the professors). A 2010 study by Indiana University (IU 2010) highlighted the impact of the impact of this approach, finding that 30% of scientists were concerned enough with their in-house tech transfer office to take a "backdoor" route to commercialization (routes which, by the way, were also more successful). This matter aside, federal funding of tech research has increased while pure science research funding has remained steady — a byproduct of a policy focus that prefers funding research with patentable components. This focus is predictable, but it doesn't need to be permanent. Huge swaths of science research are overlooked by tech transfer offices and opportunities to integrate discoveries, apply new methods, and more haven't been pursued. And this extended reach doesn't end with pure science. The world also needs innovation in anthropological and geopolitical perspectives, economics insight, and more. Tech transfer offices can be in a position to help integrate university knowledge — to be knowledge transfer centers more so than simply technology licensing centers.

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LACK OF CIVIC ENGAGEMENT

Science doesn't do a good job across of the board of connecting with the public and this fact affects everything related to science, from research funding to policy to education. At the same time, many have observed that (for reasons not entirely understood yet) those who are skeptical of science are held to a lower standard of proof and are increasingly gaining in influence. There are exceptions, of course, but improving the civic engagement ability of science is important to our future. How can this be done? By integrating communications into the framework of science. This doesn't necessarily mean spending more money, just changing how it's spent. The resulting increase in research effectiveness and efficiency could be startling. The basis for this recommendation is simple: Without adequate communications support, science simply can't explain complicated issues to the media in a compelling way (Holland 2010). This is just a common sense finding for business professionals, of course; Steve Jobs never expected a single research team of Apple engineers by itself to design a product's electronics, information architectures, user interfaces, industrial designs, packaging, and marketing campaigns. Building and rolling out successful science and technology takes a village. In marketing and communications firms, teams of experts work together to distill their client's key messages, edit and tailor language, produce graphics, identify audiences, contact opinion leaders, and more. And yet in science we expect a researcher who may be an expert in climate change to go on CNN and change public opinion by herself by sheer force of intellect. It's an unfair expectation, and one that clearly doesn't work.

But the engagement capacity of science has more than just institutional barriers. There are time barriers as well. A 2000 report by Wellcome revealed that many scientists feel too constrained by the day-to-day requirements of their jobs to even carry out their research let alone oversee more sophisticated communication strategies (Wellcome 2010). What if time wasn't an issue though, and this new communications work was handled by outside experts? Then how would scientists feel about getting communications help? Scientists today feel they are expected to discuss how science affects society — particularly in hot-button fields like stem cell research and climate change — but most are unprepared or unwilling to do so (Mizumachi 2011). Indeed, most complain about the experience of science communication activities. In addition to the time constraints they perceive a lack of support from peers and little career benefit. Very few surveys, meanwhile, have focused on the difficulties, barriers and motivations encountered by scientists in public science communication. More information is needed so the appropriate kinds of assistance can be offered to scientists and the right kinds of "cultural" changes to research institutions and funding agencies can be promoted and developed. It's important to note that in the Wellcome report, most scientists reported being unaware of existing communications support offered by their funders or institutions that they could utilize.

Still, building true civic engagement in science may require more than just improving the communications capacity of science. American University's Matthew Nisbet argues — speaking specifically to the issue of climate change — that our vision of science communication wherein "Americans are spectators in a political system where decision-making on climate change is handled by experts, policymakers, environmentalists, and industry" needs to be changed (Nisbet 2010). He argues that the goals of science education need to be much broader, with an emphasis on *civic education and engagement,* which means "empowering, enabling, motivating, informing, and educating the public around not just the technical but also the political and social dimensions of climate change."

"Besides cultivating a broader range of knowledge," he writes, "civic education requires promoting affective outcomes such as increased feelings of trust and efficacy; investing in a new communication infrastructure and participatory culture; and recruiting citizens who can help their peers learn, connect, and plan." In addition, unlike the emphasis on science literacy which is one-directional and focuses on a "knowledge deficient" public, civic education and engagement "is as much about informing the public as

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it is about informing experts and decision-makers." Education in this paradigm is "a two-way process where experts and decision-makers seek input and learn from the public about preferences, needs, insights, and ideas relative to climate change solutions and policy options."

Of course, the mere availability of information doesn't mean the public will use it or use it uniformly. Knowledge gaps have developed along socioeconomic and ideological lines because we no longer get our news from the same sources and these different sources have so many different biases. However, more information, more effective information presentation, and more civic engagement are good developments and will only help solve the problems discussed in this paper. Knowledge gaps and differentiation are different problems altogether that affect far more than just science education.

ADDITIONAL PROBLEMS

Changing the culture and practices of communication in science won't happen overnight. There are numerous challenges to overcome. Some of these challenges have already been described, but many more have only been hinted at. For instance:

- PRESSURE FROM DIGITAL NATIVES: Scholarly communications is currently in a halfway state between the digital and print world, with print still being far more influential (Bourne 2011). In the meantime, new researchers have arrived in science who were born into a world that has always had powerful desktop computers, the Internet, and free and easy access to a world of information. It's reasonable to expect there will be increasing pressure from these digital natives for change from within science. But in an environment where knowledge is currency, significant and rapid change is unlikely to occur without a broad understanding of the issues and agreement on the solutions. Can a "safe" environment be constructed throughout science that will allow a new communications paradigm to develop?

- RISK-AVERSE CLIMATE: Since the current reward system in science is tightly coupled with journal impact factors and citation measures like the Hirsch Index, scientists tend to be risk-averse when they are experimenting with new models of scientific communication (Velden 2011).

- SCIENTIFIC SOCIETIES: Will scientific societies support new communication models? Their missions support doing so, but their business models may not given that they also publish major journals.

- PRIVATE INDUSTRY RESISTANCE: Publishers and other commercial entities own mountains of content. It varies by discipline — chemistry data is almost entirely locked up behind pay firewalls (Adams 2009) — but for the most part, these entities need to collaborate in any new information sharing system and in supplying new data repositories with older information.

- PATIENCE: The benefits that will accrue from improving the default communication posture of science will take time to be realized. But in our bottom-line driven funding climate where results need to be proven quickly and the pressure to cut "non-essential" budget items is high, there may be little patience for allowing enough time to prove the worthiness of this concept.

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THE BASIC SOLUTION

The alternate reality world of cooking described earlier in this paper is utterly unfamiliar to us today, but it's actually not that far-fetched: cooking was once a much more exclusive enterprise than it is today, and the birth of an industry occurred because of access. Books like *The Joy of Cooking* and celebrities like Julia Child helped democratize and popularize the culinary arts, making cooking accessible and spurring innovation, sharing, participation, understanding, excitement and development in the culinary industry.

Awareness of the communication problem in science is also growing today but only in specific areas and only in fits and starts. There isn't widespread acceptance yet of the right role of communication in science, nor is there widespread recognition yet that science communication is a unique discipline as discussed in this paper's introduction. However, there are glimmers of hope. A recent study (Jensen 2008) revealed that scientists who make civic engagement a priority are also more academically active, perhaps because their work helps stimulate and promote their research. Big data is also beginning to gain traction. Companies and venture capitalists are embracing the possibilities with zeal, making big data one of the hottest IT investments in 2012, and big data could soon be at the leading edge of discovery in data-intensive science like genomics research. Elsewhere, a number of focused efforts are underway to address other parts of the science communication problem, including courses that help scientists communicate better, organizations dedicated to improving science writing and STEM education, growing discussion sites for scientists, and nascent movements to reform the academic journal publishing system (including the recent 2012 boycott against Elsevier; see Bell 2012 for more information).

With respect to the publishing issue, more OA publishing resources are being established (the online OA journal PLoS ONE is now the world's largest repository of peer-reviewed research work), more universities are setting up their own OA repositories, and large commercial publishers like Nature and Springer are increasing their OA offerings. OA publishing in PubMed Central has long been required for all NIH-funded research. What more can be done? Some have argued, for instance, that all works funded by federal research dollars—not just NIH research—should be OA: if taxpayers pay for it, they should own it. Others have advocated reforming the journal system and its ties to tenure altogether. Does the gold standard for what constitutes a "research object" need to be a journal article, or can we utilize some other mix of measures (Bourne 2011)? And does anonymous peer review (the current system) work just as well as more open methods? Already in use with some journals, open review means publishing reviewer comments along with the manuscript in an online discussion forum, the scientific community gets invited to join the debate, and after a period of a few weeks the authors are asked to revise or defend their manuscript based on feedback (Velden 2011, Pöschl 2008).

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Tech transfer efforts are also garnering more attention as universities look for more sources of revenue to offset shrinking budgets. Recently released recommendations from the Association of University Technology Managers (AUTM) to the Obama Administration include funding tech transfer offices directly, funding proof-of-concept centers where ideas can be test-driven before going to market, funding mentorship programs, and offering tax credits for investments in early-stage companies. Giving science research more attention instead of only patentable technology will also be important. Whether or not this attention leads to rapid marketplace applications shouldn't be the only metric of success since getting more of a birds-eye view on fundamental innovation and integration will also pay dividends in both the marketplace and for discovery. Tech transfer offices will need to gear up for this kind of reinvigorated involvement, though, which won't be possible for most universities in today's austere budget environment. For most offices, patentability and marketability will likely remain the ultimate measure of merit in science. More on tech transfer will be discussed in a future nSCI White Paper.

nSCI's SOLUTION

The thoughtful work and attention that many individuals and organizations are now turning toward the issues described in this paper will eventually produce change. The goal of nSCI is to help organize this change by raising awareness of the issues involved among science communities and science funding agencies, build communities of individuals and organizations who support this change and will make change occur, and provide both funding support and best practices guidance to help make these changes widespread, sustainable, visible and effective.

It's important to emphasize that this cultural shift that needs to occur in science won't happen by simply writing papers about it. This shift needs to be encouraged and supported by five actions — actions that are at the heart of what nSCI is doing. These actions are listed in the left column of the following table. The specific activities nSCI is currently undertaking to help improve science communication are listed in the right column.

The longer-term projects nSCI undertakes and the scope and timing of these projects depends on the organization's funding outlook. nSCI is currently in the early stages of growth and is still building its major sources of financing. To help support nSCI, please visit www.nationalscience.org.

GENERAL ACTIONS NEEDED	SPECIFIC NSCI ACTIVITIES
1. Increase awareness of the importance of better communication throughout science	• Drive change in how communication needs to be better integrated into the framework of science research • Continuously speak with stakeholders to get feedback and learn about and share new ideas, initiatives, and success stories in science communication. • Facilitate conversations about current communication practices (such as journal publishing) to help develop new approaches to ensure better information access
2. Share lessons of experience and best practices	• Create, collect and promote conversations on best practices in science writing, marketing, collaboration, education, policy, design, informatics, and tech transfer, and drive connections between these disciplines • Publish and distribute the first book on this topic
3. Build communication communities	• Serve as a resource hub, information portal, and umbrella group for the many organizations currently involved in science communication-related work • Create, manage, and grow communities of scientists, informatics experts, educators, and others who are interested in improving science communication
4. Provide tools and assistance	• Create free but managed data-sharing resources to ensure data comparability • Subsidize the marketing and communication needs of science research, STEM education, and other science-related projects with broad potential impact
5. Prove the worthiness of this approach	• Document the success of more efficient and effective communication methods in science and promote this information within science and also to donors and policymakers.

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Additional reading links:

- Tenue trends: http://arstechnica.com/science/news/2012/02/survival-in-academia-the-tenure-track-not-taken.ars?utm_source=rss&utm_medium=rss&utm_campaign=rss
- Current tenure policies: Recommended Institutional Regulations on Academic Freedom and Tenure from the American Association of University Professors
- List of OA journals in all fields and languages: Directory of Open Access Journals
- Searchable database of publisher policies about copyright and archiving: Project SHERPA.