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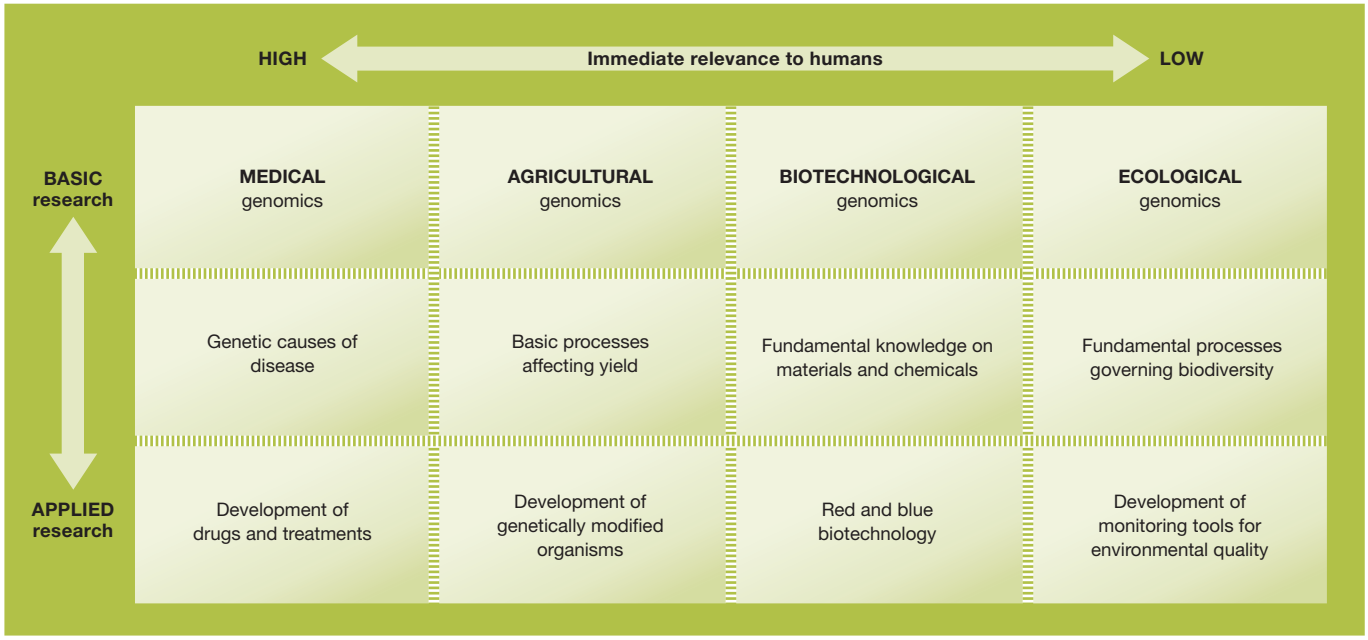

Fig 1 | The horizontal continuum describes the immediate relevance to humans, which goes from high (left) to low (right), whereas the vertical continuum goes from basic (top) to applied (bottom) research.

began, researchers claimed that finding cures would only be a matter of time, once we knew the genetic causes of many diseases. At the same time, there was, and still is, a growing public demand for quick solutions to a wide range of complex and debilitating diseases, including cancer, coronary heart disease and diabetes. However, it quickly became clear that identifying the genetic causes of disease and, more importantly, developing adequate therapies is, in fact, enormously complex.

Although medical genomics has generated many important results—including identifying the genetic component of several diseases (Merikangas & Risch, 2003; Kaiser, 2006) and providing the full sequence of the human genome (Venter *et al*, 2001)—it is becoming increasingly clear that those early claims for simple cures were overoptimistic. Even with the sequence of the human genome in hand, it is still not yet possible to identify easily the faulty genes at the root of many diseases. Moreover, even if we were to discover such factors, finding a cure remains anything but a trivial task. Society, meanwhile, is becoming rather impatient and slightly disappointed; even pharmaceutical companies are now questioning whether their investments in genomics were truly justified (NGI, 2006).

The purpose of the foregoing is not to question the achievements of medical genomics; on the contrary, no matter the original claims and expectations, the achievements in this field are huge and of invaluable importance. My intention is rather to illustrate how and why communication might go wrong when various parties have different needs and expectations. A full analysis of this topic falls beyond the scope of this paper, although we can still draw some fundamental conclusions. In short, it seems likely that part of the problem has been that medical genomics all but promised to solve society's disease woes in an attempt to justify investment, while society wished for unrealistically quick and easy solutions to what have turned out to be immensely complex problems.

From this point onwards, I will adopt the point of view of the natural scientists working in genomics, and analyse their needs and expectations when they communicate with society. Before I do so, however, I need first to define what exactly I mean by a 'genomicist'. At first glance, genomics seems to be quite a homogeneous discipline; however, it actually encompasses a wide variety of approaches, disciplines and sub-disciplines. For example, genomic researchers might be geneticists, molecular biologists, bioinformaticians, ecological genomicists or microbiologists, all of whom contribute their own expertise and experimental approaches.

The genomics community can also be described in terms of a continuum of objects of study and goals. The objects range from microorganisms, including viruses to lower organisms, and upwards to plants, animals and humans. When it comes to defining the goals of genomics, the field can be categorized along two independent axes (Fig 1): the first is a gradient from high to low immediate relevance for humans, whereas the second is a continuum from strictly basic to strictly applied research, as mentioned earlier in this paper. Given this wide variety of goals, objects and disciplines, it should be clear that we ought not to expect a single, general set of needs and expectations to be at play when genomicists communicate with society. Obviously, a researcher working on drug development for a particular disease will have a completely different need for communication—and a different set of expectations—than, for example, an ecological genomicist, who is interested in biodiversity.

Communication is essential for scientists and scientific research; advances and achievements in science depend on its success at various levels. First, scientists need to communicate information and ideas with colleagues from other disciplines, which is especially important in a new and highly multidisciplinary field such as genomics. As detailed above, the genomics community

consists of many disciplines, each of which has its own vocabulary, research and publication culture and dynamics. Communication, even between scientists, is not a trivial task.

In fact, promoting interdisciplinary communication has been identified as one of the targets for the development of ecological genomics (eco-genomics; Ouborg & Vriezen, 2007). In this field, molecular biologists and ecologists work together on questions about the diversity of life, although, of course, these two scientific disciplines have different research cultures and paradigms. Molecular biologists are used to a relatively rapid pace of research and publication; they tend to reduce the complexity of the natural world to manageable pieces by working with model species in the highly controlled environment of the laboratory. This approach has been successful in discovering many functional aspects of genes and their activity; it has, for example, yielded highly detailed information about how diseases are associated with certain genes. Ecologists, by contrast, are used to working more slowly: the development of their objects leads to a relaxed pace of publication, and they tend to embrace the complexity of the natural world in their approach, rather than try to reduce it. Perhaps most telling are the typical responses of either type of scientist to a failed experiment: molecular biologists typically search for the cause in not having reduced or controlled complexity enough, whereas ecologists try to find the answer in increasing complexity and including more factors. To work together in a viable eco-genomics research programme, these two disciplines need to develop a good understanding of each other's language and way of thinking in order to be able to communicate efficiently.

Second, scientists need to communicate with peers in their own research field. Genomic methods allow for fast results and often, easy repeatability, which limits open communication—sharing information is not a desirable strategy in a competitive world. This is particularly true with regard to applied research—there are implicit and explicit rules on what can and cannot be communicated with peers. One example was the huge collaboration that resulted in the sequencing of the human genome; a task so formidable that it was only possible—certainly at that time—by sharing the work between many parties. However, because it involved public partners such as research institutes associated with public universities—the University of California, USA, Penn Sate University (Philadelphia, PA, USA) Johns Hopkins University (Baltimore, MD, USA) and Yale University (New Haven, CT, USA)—and private partners, notably Celera (Rockville, MD, USA), communication was far from open and effective owing to commercial, property and patent issues (Davies, 2002).

> **…society has wished for unrealistically quick and easy solutions to what have turned out to be immensely complex problems**

Third, scientists also need to communicate with societal partners, usually for one of two reasons. First, genomicists often initiate communication when they need something from society: either materials and money, or societal acceptance of new techniques or approaches—such as the approval to work with human stem cells or to perform research with GM organisms. Second, society can initiate communication when there is a specific need for information—the answers to pressing societal questions, such as the cause of certain diseases or the risks of trans-genetic modification. This category also includes the demand for new products: drugs, therapies, monitoring tools or the development of biotechnological products. Obviously, these various goals greatly determine the need for communication by both parties, and there is limited scope for motivations to overlap. In other areas, in which motivation does not match at all, communication is complicated.

It is also helpful to clarify the driving forces behind each individual researcher's need to communicate. To that end, we must distinguish the different tasks of scientists. First and foremost, their task is to develop knowledge, either from a fundamental perspective or to solve a problem. The second task is to find support for their work, usually by writing grant applications. This is true for both basic research, in which society needs to be convinced of the importance of the topic, and applied research, in which researchers need to convince funding bodies that they are 'the best person for the job'. A third important task, at least for researchers at universities, is teaching. The transfer of knowledge to a new generation of scientists is a form of communication that falls outside the scope of this paper, but which might be the most important form of communication for the majority of scientists.

A scientist's performance is measured by how well he or she performs at these various tasks. The most prominent evaluation criterion for any scientist is his or her publication record and/or citation index. This places a great deal of pressure on writing publications—a task that then dominates all others in most cases—although, of course, attracting funding does improve the scope for a good publication record. The main motivation to communicate is therefore a function of both tasks: publishing and attracting funding.

In general, researchers are highly motivated to communicate if they need something, either from society as a whole, or society as represented by government or funding agencies. Explaining the importance of research to the general public and policy-makers is an important way of promoting a particular topic to secure funding, and/or to set a research agenda that is favourable to one's own work. But, the degree of motivation fully depends on the expected payoff in terms of publications and funding. As such, it is mainly a stimulation of one-way communication: from scientist to society. Moreover, scientists are not rigorously evaluated on how well they respond to questions from society, although grant proposals and evaluations do require them to list their societal communication and knowledge dissemination activities. However, in many institutions, little official time is allocated for such tasks and the degree of official appreciation of these activities varies greatly. There is little structural organization available to support

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This article is part of the *EMBO reports* Science & Society Series on Convergence Research, which features Viewpoints from authors who attended the 'Doing Society and Genomics—Convergence and Competence Building' workshop organized by Peter Stegmaier for the Centre for Society and Genomics at Radboud University (Nijmegen, the Netherlands) in September 2008. We hope that this Viewpoint series will help to introduce our readers to the new multi- and transdisciplinary developments among the life sciences and the social sciences and humanities.

scientists in this regard and communication is often based on personal motivation, rather than institutionalized programmes.

Communication between society and genomics is a complex, multifaceted process. Assuming that all researchers have the same needs, expectations and motivations does not acknowledge the reality of this multidisciplinary field. Designing programmes to enhance communication between genomicists and society should therefore take these aspects into consideration. Boundary workers—being the ultimate intermediaries—are optimally equipped to clarify the needs, expectations and motivations of both scientists and society.

One way in which to enhance and encourage two-way communication between genomicists and society would be to raise further its importance in the evaluation criteria used to assess scientific achievement and approve grant proposals. In this way, the immediate benefit of communication strategies and efforts would be clear to individual researchers and institutions, and we might expect that greater effort would be put into providing the time and facilities for researchers to perform this task. However, it might also be that the emphasis that society places on direct results and 'value for money' could dampen a researcher's motivation to do anything that would not directly benefit their activities.

Communication programmes for genomics and society should certainly inform society about the achievements, risks and potential of genomics. However, the design of any programme should also keep in mind the need for scientists to 'sell' their research to the public and funding agencies. A lack of efficient communication, or motivation, from the side of the scientist in the past has been interpreted in the light of the so-called "cognitive deficit model" (Irwin, 2006). It explains non-optimal communication by placing emphasis on the idea "that lay people are ignorant about scientific facts" (Marris *et al*, 2001).

Here, I want to hypothesize that part of the miscommunication might be understood from what I call an "obligatory immediacy model": there is a strong tendency in society to focus exclusively on immediate and pressing problems, and only demand scientific communication in these cases, while neglecting and even ignoring other areas. Although it is important to undertake public activities that discuss pressing societal issues with scientists—as is often done in the field of genomics—it is equally important to organize activities in which scientists can just explain their fascination with genomics and their research activities to society, without any immediacy pressure. These activities should be designed according to the variety of genomicists as outlined in Fig 1. It is more profitable, for example, to organize a scientific meeting in which applied medical genomics research is explained and discussed with a particular patient group, or in which basic eco-genomic research is discussed with environmental policy-makers, than to organize activities under the general term 'genomics'.

For boundary workers in the field of genomics and society, it is also important to take into account the diversity of genomicists, and their needs and expectations. A fundamental eco-genomicist is likely to respond differently to a general questionnaire than an applied medical genomicist, for the simple reason that they belong to different subsets of the community. Ignoring this diversity would lead to erroneous conclusions.

In conclusion, the following points should be taken into consideration in any effort to increase the motivation of genomicists to communicate. Foremost, any effort that scientists make to participate in two-way communication with society should be acknowledged and should represent an integral part of the scientific assessment procedure. Moreover, the actual success of these attempts should be evaluated and rewarded where appropriate. At the same time, the nearly total emphasis on scientific publication needs to be reduced, albeit publication is likely to and should remain an extremely important form of communication and assessment.

Communication activities should not only address pressing societal issues, but also allow for a detailed explanation of science that has little societal urgency. It should match the appropriate genomicists and societal groups, and take into account the diversity in both groups. Another helpful activity would be the creation of genomics-society forums, in which matching scientists and societal interests come together on a regular basis to inform each other continuously. Participation in these forums should again be an evaluation criterion for scientists. Finally, genomicists should be trained in how to communicate with society. Most communication programmes take a 'genomicists for society' approach; this should be complemented with activities taking a 'society for genomicists' approach.

Several of these activities are already under way, but not all are as efficient as we would like them to be. A change of attitude from both society and scientists is needed. In an ideal world, the two groups would share and acknowledge their specific needs and expectations, and, paying attention to these needs and expectations would facilitate effective communication.

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