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Identifying creative research accomplishments: Methodology and results for nanotechnology and human genetics

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Motivated by concerns about the organizational and institutional conditions that foster research creativity in science, we focus on how creative research can be defined, operationalized, and empirically identified. A functional typology of research creativity is proposed encompassing theoretical, methodological and empirical developments in science. We then apply this typology through a process of creative research event identification in the fields of nanotechnology and human genetics in Europe and the United States, combining nominations made by several hundred experts with data on prize winners. Characteristics of creative research in the two respective fields are analyzed, and there is a discussion of broader insights offered by our approach.

Introduction

After an expansion of the research system in industrialized nations in the 1970s and 1980s, research and development (R&D) spending as a proportion of gross domestic product changed little in most of these countries over the last decade (NATIONAL SCIENCE BOARD, 2004: p. 4, pp. 49-50). However, there has been a substantial evolution in the institutional and organizational conditions under which scientific research is conducted. For example, public research funding was traditionally allocated

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through long-term institutional block grants to research laboratories and through disciplinary awards to individual academic scientists; today competitive project funding has grown considerably and there is also a greater emphasis on fostering organized research centers, networks, and interdisciplinary teams. Moreover, in addition to peer review, evaluation systems for research performance have been increasingly implemented (SHAPIRA & KUHLMANN, 2003).

In the context of heightened competitive pressures to foster science-driven business development and the rise of new global locations for research (especially China), research policymakers in developed economies hope that adjustments to institutional and organizational environments for scientific research will promote not only more efficiency but also boost scientific excellence and creativity (BLAU, 2005). Changing institutional and organizational conditions for conducting research probably will have effects on how creative research is accomplished. Yet, the relationship of organizational and institutional factors to research creativity is still a relatively under-studied subject. While creativity research (focusing on individual traits) is an established field in psychology and there is a burgeoning literature on creativity in business, studies in both the sociology of science and science and technology (S&T) policy have paid less attention to research creativity in science in recent years.[1] Consequently, if we want to advance our understanding of the dynamics of science at research frontiers, we need to know what creative research accomplishments are, where they occur most often, how we can identify them, and which organizational and institutional factors are conducive to creative research.

In this paper, we address two pivotal methodological problems for the study of research creativity. First, how can creative research be defined and operationalized? Second, how can creative research be identified empirically? Work on both problems is necessary prior to addressing the subsequent research question on the organizational and institutional conditions of creative science.

With regard to the first question, we propose a typology that embraces five types of creative accomplishments in science. While our methodological approach shares some common aspects with previous literature, it also deviates from it. For example, in contrast to Sternberg's emphasis on whether research contributions accept or leave paradigms, and whether they move the field in the direction it is already going or in a new direction (STERNBERG, 2003), our typology captures functional characteristics of novel and unconventional research, such as theoretical enhancement and synthesis, new methodology, or new research instrumentation.

With respect to the second question, we present a methodology that identifies scientific creativity using a different – and broader approach – than attempted in previous studies. For instance, HOLLINGSWORTH (2002; 2004) and ZUCKERMAN (1977)

[1] For an exception, see: HEMLIN et al., 2004.

examine laureates of prestigious awards, while SIMONTON (1999; 2004) and SEGAL et al. (1980) rely primarily on publication and citation data. Again others capture creative research by online observation methods (DUNBAR, 1995; 1997). In contrast, we rely first on nominations of highly creative research collected for two research fields through an international survey. In this survey, several hundred experts, among them highly cited scientists, active researchers from academia and industry and editors of major research journals, were asked to nominate highly creative research accomplishments in their respective fields. Second, we relate these nominations to a database of scientific prize winners in the two fields and derive various categories of creative researchers. Both the nomination and the prize winner databases are examined to retrieve aggregate information on topics and subfields that constitute areas of current creative accomplishments in the two research fields.

This paper is part of an international study on research creativity that aims at understanding the institutional and organizational conditions that influence the frequency with which creative research is accomplished in today's scientific research. For comparative purposes, two research fields were chosen: first, nanoscience and nanotechnology (referred to as "nano S&T" in the rest of the paper); and, second, human genetics. Nano S&T is relatively young domain of scientific endeavor and embraces heterogeneous research areas, such as applied physics, materials science, physical chemistry, physics of condensed matter, biochemistry and molecular biology, and polymer science and engineering. In contrast, human genetics is comparatively mature and has its roots in biology, biochemistry, and medical sciences. Both research fields are similar in that they constitute fields of science which have the potential to lead to technological innovations and where processes of technological innovation are strongly connected to cognitive innovations in scientific research.

The next section reviews definitions of creativity and concepts of creative research, and discusses how others have operationalized and identified creative scientific achievements. We then present our typology of creative research and our methodology for identifying creative research products. After a discussion of empirical results, the concluding section summarizes the approach and discusses implications and insights gained.

Research creativity: Literature review

Definitions and concepts

Creativity is generally defined as the capability of human beings to do things that are novel, original, valuable and unexpected. OCHSE (1990: p. 2) summarizes the many existing definitions by stating that creative products are "original (new, unusual, novel, unexpected) and also valuable (useful, good, adaptive, appropriate)." AMABILE

(1996: p. 35) has introduced the concept of "heuristic tasks" as opposed to "algorithmic tasks" to emphasize the uncertainty and the unexpectedness of the outcomes of creative processes. STERNBERG (2003: p. 89) defines creativity most comprehensively as "the ability to produce work that is novel (that is, original, unexpected), high-quality, and appropriate (that is, useful, meets task constraints)."

There are a number of other related terms and concepts that make up the cognitive-conceptual space in which creativity is embedded. These include talent, thinking, insight, imagination, inspiration, ingenuity, innovation, intelligence, inventive, virtuosity, excellence, learning, discovery, experimentation, risk-taking, and avant-garde. Some of these analogous terms refer to the creative product, such as an insight or a discovery. Others point to aspects of the creative process, such as experimentation or risk taking, in the course of which novel and unexpected outcomes are incorporated into an existing stock of knowledge and know-how via learning or socialization. Again other terms mention individual traits necessary to engage in creative activities, such as imagination, intelligence and talent.

Creativity is of considerable importance in many areas of society. Creativity as human work that is novel, original, valuable and unexpected occurs in multiple societal domains. Creativity is the foundation of the arts (MARITAIN, 1977; BERKA et al., 2003), but is also found in the domains of politics (NAGEL, 2002; OTTEN, 2001), private business (SUTTON, 2002), and science (HOLLINGSWORTH, 2004; SIMONTON, 2004). In all these fields of human activity, standards of excellence develop, against which new processes and products domain are appraised. In the world of science, such standards of excellence are set by scientific disciplines and scientific communities as the main cognitive and social structures for knowledge generation and accreditation (WHITLEY, 2000). So, one might assume that major progress in research takes place within disciplinary structures and within established scientific communities. Polanyi believes that a strong disciplinary grounding is an important basis for progress in science. Discoveries are made by scientists pursuing unsuspected possibilities suggested by existing knowledge. Scientists who transmit this belief to their students give them the basis on which to develop their own discoveries – even in opposition to their own teachers (POLANYI, 1966).

Yet research judged favorably by peers is not always creative, while creative research is not always initially accepted by peers. There is tension inherent in the criteria used to judge scientific merit, in particular between plausibility, validation, and originality. Whereas criteria of plausibility and scientific validation encourage conformity, the importance attached to originality encourages dissent, because although scientific originality springs from scientific tradition, it also supersedes it (POLANYI, 1969). One interesting example of this tension is Max Planck's quantum theory: "Although many striking confirmations of (Planck's theory) followed within a few years, so strange was Planck's idea that it took eleven years for quantum theory to gain final acceptance by leading physicists" (POLANYI, 1966: p. 67). More recently, Binnig and Rohrer's work in developing the scanning tunneling microscope (for which they were awarded the Nobel Prize in 1986) was in the beginning rejected by some scientists and paper reviewers with disbelief (HESSENBRUCH, 2004). Similarly, George Akerlof's path-breaking contribution to the economics of asymmetric information and adverse selection was initially rejected by three major economics journals (SWEDBERG, 1994). These examples show that novel and thought-provoking contributions do not always resonate positively within the scientific communities. The scientific community must be persuaded that the novel and unexpected contribution has value in the domain of research.

While scientific research creativity may take time (as well as effort) to be fully recognized, the underlying rationale of this particular branch of human activity is to search for new and unexpected knowledge (LUHMANN, 1990). Research activities explore new territories both in the sense of gaining new fundamental knowledge but also extending the control of matter. Creativity in scientific research has traditionally been studied from various angles: products or outcomes of creative work, creative individuals, creative processes and creative knowledge environments (STUMPF, 1995; HEMLIN et al., 2004). Our focus in this paper is on creative accomplishments in science and on the scientists recognized for producing these accomplishments. The next section reviews relevant contributions that discuss how creative research accomplishments have been conceptually operationalized and empirically measured.

Operationalizing creative research

In operationalizing the concept of research creativity, Sternberg's Creativity Typology (STERNBERG, 2003) is an important and interesting attempt. Following KUHN (1962), Sternberg refers to scientific creativity by distinguishing between "normal" and "paradigmatic" science. The author introduces eight types of creativity all of which are subsumed under two major categories: contributions that accept or reject current paradigms (STERNBERG, 2003). Within the first category (acceptance of current paradigms), Sternberg distinguishes contributions that either (a) leave the field where it is or (b) move the field in the direction it is already going. Further, he splits up both the former and the latter category into two respective subcategories: (a-1) replication and (a-2) redefinition, and (b-1) forward motion and (b-1) forward progression. Similarly, creative accomplishments that reject current paradigms either (c) move the field in a new direction from an existing starting point, or (d) restart the field in a new direction from there. Here again, Sternberg divides two subcategories in both (c) and (d), namely (c-1) redirection and (c-2) reconstruction, and (d-1) re-initiation and (d-2) integration.

Sternberg's typology is an interesting starting point, but problems appear when studying research creativity empirically. To begin with, Sternberg provides some examples, but not for all the creativity types of his typology. This raises doubts about the validity of the typology. More problematic, however, is the fact that most examples are taken from psychology. Sternberg's focus on psychology might limit our understanding of the broader set of sciences including physics, chemistry, biology or material science, because there is abundant evidence that some disciplines, such as mathematics and physics are much more paradigmatic than others, such as political science or psychology. Paradigmatic sciences exhibit (1) greater consensus in peer evaluation as visible in lower rejection rates for research papers, (2) faster obsolescence of research results, (3) higher concentration of core journals, (4) lower integration of knowledge from other disciplines, (5) more co-authorship, (6) non-existence of "schools of thought", and (7) strong focus on articles but not books as medium for publication (STICHWEH, 1994; WHITLEY, 2000; SIMONTON, 2004).

The limitations of Sternberg's Creativity Typology are addressed later in this paper where we introduce a functional typology of research creativity that brings theoretical, methodological and empirical aspects of scientific research into five major categories of creative research accomplishments. Before introducing this, we discuss the empirical ways in which research creativity has been identified.

Identifying research creativity

Creative research has most frequently been identified either as publications and citations or as scientific prizes and awards. Simonton's chance figuration theory, for instance, addresses scientific creativity by providing extensive analyses of publication and citations. In this probabilistic-evolutionary perspective, creative accomplishments are regarded as low-probability events (following a Poisson distribution) that increase linearly with scientific productivity and, thus, are a probabilistic consequence of the publication quantity published by researchers (SIMONTON, 2004; 1999). Publications are seen as "ideational variations" created by individual scientists who continuously link knowledge elements from their cognitive domain (conceived as a "population of ideas" – phenomena, facts, concept, variables, constants, techniques, laws, questions, goals and criteria) into new combinations. While all scientists produce (in varying amounts) such ideational variations, only a few of these are selected as creative accomplishments by their peers. While those variations that pass several selection filters successfully (e.g. journal peer review) are retained in the collective stock of knowledge, most of the publication output will be forgotten, i.e. not be cited at all.

The interesting point in Simonton's analysis is his claim that "future Nobel laureates can be predicted on the basis of the total number of citations candidate scientists receive to their body of work", and further, that "the single most critical predictor of citations is the total number of publications" (SIMONTON, 2004: p. 19). According to the author, the intertwined relationship between the probability of creative accomplishments in science and individual research productivity pertains to scientific domains as diverse as mathematical logic, physics, biology, psychology, and technology (SIMONTON, 2004: p. 25). Therefore, “journal articles provide an objective basis for defining the creativity of scientific products” (SIMONTON, 2004: p. 17).

Although Simonton’s chance figuration theory can be understood as a comprehensive effort to shed light on the statistical properties underpinning both idea variation and selection across individual scientists and disciplines (e.g. distribution laws, multiple discoveries), it allows only probabilistic statements on where and by whom creative research is accomplished. While predicting highly creative ideas (low-probability events) from publication and citation measures appears an interesting approach, there is little evidence that this is feasible, and even if it was, we do not know whether the contribution was a theoretical advancement and how it related to current theory, or if the accomplishment was the discovery of new empirical phenomena, or if it included the development of new research methodology or instrumentation. Therefore, publication and citation data measures need to be accompanied by other approaches if creative research accomplishments are to be operationalized and identified properly. This conclusion is confirmed by empirical research which highlights the complexity of the relationship between citation rates and researchers’ perceptions of the scientific contribution of specific publications (AKSNES, 2004).

Hollingsworth’s sociological study on research creativity in the biomedical sciences is based on an alternative data source (HOLLINGSWORTH, 2002). This study deals exclusively with research organizations, most importantly the Rockefeller Institute and the California Institute of Technology, that have produced a continuous stream of research breakthroughs as manifested in prestigious scientific prizes, such as the Nobel Prize in Physiology, Chemistry and Medicine, the Copley Medal, the Arthur and Mary Lasker Prize, the Louisa Gross Horwitz Prize and the Crafoord Prize. All these prizes represent considerable achievements in science, and Hollingsworth is certainly right in assuming that awards of this reputation capture an important share of the research breakthroughs in the biomedical sciences.

Yet such highly reputed scientific prizes are also extremely selective, both in the sense that they can be conceived as final filters for selecting creative combinations from ideational variations, and in that there are many more candidates whose contributions deserve a prize. However, as the number of prizes is limited, many candidates have not received one in their lifetime. It is precisely the latter objection Hollingsworth takes into account when including Nobel prize nominations in his study, i.e. shortlists of discoveries considered to be “prize-worthy” by the Nobel committees which did not earn the respective scientist the Nobel prize though. As such nomination data displays a much broader set of scientific accomplishments compared to lists of factual prize winners, it is extremely valuable but, for obvious reasons, often not disclosed. The Nobel Archives at the Karolinska Institute and the Royal Swedish Academy of Sciences only permit access to the committee's shortlists for Nobel prizes that were awarded more than 50 years ago (HOLLINGSWORTH, 2002). Therefore, Hollingsworth's study refers to scientific accomplishments of the first half of the 20th century, but gives no insights into more recent scientific breakthroughs of today's research labs.

In our work, we seek to address the limitations of studying research creativity by reference (a) solely to publications and citations or (b) to a relatively small (albeit prestigious) set of prizes that do not facilitate an up-to-date and comprehensive view of research creativity. The conceptual core of this work is the development of a functional typology of scientific research creativity that facilitates new kinds of measurements. An integral part of this methodology is the development of an additional data source: an international nomination survey that asks knowledgeable experts and scientists to identify recent creative scientific accomplishments in two research fields. As will be seen, we complement this with an extended database of prizewinners.

Typology of creative research products

Against the background of the discussion in the previous section, we suggest a functional typology of research creativity that brings theoretical, methodological and empirical aspects of scientific research, each of which has a different function in the research process, into five major categories of creative research accomplishments Table 1.

Table 1. Typology of scientific research creativity

Type of scientific research creativity		Examples
1	Formulation of new ideas (or set of new ideas) that opens up a new cognitive frame or brings theoretical claims to a new level of sophistication.	Theory of specific relativity in physics (EINSTEIN, 1905)
2	Discovery of new empirical phenomena that stimulates new theorizing	Biodiversity → Theory of evolution (Biology), DARWIN (1859)
3	Development of a new methodology, by means of which theoretical problems can be empirically tested.	Factor analysis → Theory on mental abilities (Psychology), SPEARMAN (1904a, 1904b, 1927)
4	Invention of novel instruments that opens up new search perspectives and research domains.	Scanning tunneling microscopy → Nanotechnology (Physics), BINNIG & ROHRER (1982)
5	New synthesis of formerly dispersed existing ideas into general theoretical laws enabling analyses of diverse phenomena within a common cognitive frame.	General systems theory (Biology, Cybernetics, Sociology), BERTALANFFY (1949), ASHBY (1956), LUHMANN (1984)

Source: Authors.
Note: Examples of research creativity given with year of the publication (or patent) commonly associated with the scientist's accomplishment.

The first category of our typology comprises the formulation of new ideas (or new sets of ideas) that open up a new cognitive frame. While this first type of scientific research creativity is motivated by efforts to explicitly solve theoretical problems our second category refers to new theories that are stimulated through discovery of empirical phenomena which cannot be explained within the framework of existing theories. An example of the first category of scientific research creativity is Einstein's special theory of relativity (EINSTEIN, 1905). In this paper, Einstein pursues an approach different from that of his contemporaries. His theory of the propagation of light and matter is based not on the explanation of experimental findings, but on two postulates (the postulate of relative motion and the postulate of the constant velocity of light) combined with algebraic derivations. Following its exposition, the special theory of relativity provided a fundamental framework from which a series of other interrelated theories could be deduced or experimentally derived (see STACHEL, 2002; KAKU, 2005; and references to Einstein and the special theory of relativity in *Hutchinson Dictionary of Scientific Biography*, 1999).

By way of contrast, the second type of scientific creativity is exemplified by the empirical research of naturalist Charles Darwin on fossils and species observed during the voyage of H.M.S. Beagle to South American and the Pacific in the first part of the nineteenth century. These empirical observations led Darwin to develop the theory of natural selection of species (DARWIN, 1859). In turn, these ideas subsequently stimulated new theorizing and research studies in multiple domains of science (see also reference to Darwin in *Hutchinson Dictionary of Scientific Biography*, 1999).

Our third type of scientific research creativity is the development of new methodologies by means of which theoretical hypotheses and problems can be empirically tested. An example of this type is the development of factor analysis – a mathematical technique for calculating the relative importance of each of a set of factors that together are assumed to influence some observed set of values or properties. Charles Spearman, psychologist and statistician, developed the original methodology for factor analysis to interpret the results of intelligence tests (SPEARMAN 1904a, 1904b; see also discussion in LOVIE & LOVIE, 1993; and WILLIAMS et al., 2003). Spearman used factor analysis not only for analysing results of ability tests but also to develop theories about mental testing and intelligence, most notably the two-factor (also known as the "g") theory of intelligence (SPEARMAN, 1927). Spearman's work is credited as providing "the catalyst for most intelligence theories (both in supportive and contradictory versions) developed over the past century" (STRELAU, 2000, cited in WILLIAMS et al., 2003).

The fourth type of scientific research creativity in our classification is the invention of novel instruments that open up new search perspectives and research domains. We propose as an example the patented invention of the Scanning Tunneling Microscope (STM) by physicists Gerd Binnig and Heinrich Rohrer (BINNIG & ROHRER, 1982).

Whereas scientists had previously built instruments that provided information about surfaces averaged over many atoms, the STM was novel in that it provided a three-dimensional profile of a surface at the resolution of an individual atom (HESSENBRUCH, 2004). Binnig and Rohrer were awardees of the 1986 Nobel Prize in Physics "for their design of the scanning tunneling microscope."[2] By providing the ability to study surfaces at the level of individual atoms, the STM opened up new research avenues in semiconductor physics, microelectronics, and surface chemistry. Most significantly, STM is recognized as an important tool in the emergence of nanotechnology (mid-1980s to present), giving rise to the promise of assembling materials, structures, and systems at atomic and molecular scales.

The fifth and final category of scientific research creativity is the new synthesis of dispersed ideas and concepts into general theories which then allow analyses of diverse phenomena within a common cognitive frame. The development of systems theories illustrates this category. For example, General Systems Theory was developed by biologist and system theorist Ludwig von Bertalanffy as a set of general principles that could be used to model processes of organization and development universally – in all natural sciences, engineered systems, and social systems (BERTALANFFY, 1949).[3] Similarly, the psychiatrist W. Ross Ashby, one of the founders of cybernetics, drew on systems and machine theories to develop new theories of reproducible behavior (such as the law of requisite variety[4]) which could be applied to a range of contexts, material and immaterial, involving complex processes or organisms (ASHBY, 1956). In the social sciences, Niklas Luhmann established a general theory of social systems based on networks of communication (LUHMANN, 1984). The work of other scholars in such fields as neurophilosophy, logic, mathematics, and cybernetics was important in the development of Luhmann's work; at the same time, his theory and its cognitive frame have been applied broadly, including to analyses in politics and governance, law, and science (FUCHS, 1999; WILLKE, 1996).

In presenting our typology of creative scientific research and discussing illustrative examples, we recognize that the boundaries and characteristics of highly creative research cannot always be singularly defined. For example, the discovery of new empirical phenomena may be facilitated by the invention of novel instruments, thus leading to streams of creative research accomplishments being comprised of multiple types. Similarly, we acknowledge that highly creative research breakthroughs invariably draw upon the contributions of multiple scientists, individually and as a community. This is explicitly evident in the synthetic theorizing captured in our fifth category. The

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[2] *The Nobel Prize in Physics*, 1986. http://nobelprize.org/physics/laureates/1986/index.html, Accessed March 29, 2006.
[3] See: *Ludwig von Bertalanffy (1901–1972)*, International Society for the Systems Sciences, http://www.isss.org/lumLVB.htm, Accessed March 29, 2006.
[4] Law of requisite variety, *Principia Cybernetica Web*, F. Heylighen, C. Joslyn, http://pespmc1.vub.ac.be/REQVAR.html, Accessed March 30, 2006.

major advances in systems theory in the late 1940s and 1950s drew on constructs and ideas developed over the previous one-hundred years and earlier; yet, it is also apparent that the period 1948–1960 was an especially fruitful and creative period in the development of systems and cybernetic theories, motivated by the work of scientists including Norbert Wiener and other pioneers, as well as Bertalanffy and Ashby (FRANCOIS, 1999). Analogous precursory and contemporary influences and interactions are discernable in the creative research accomplishments cited in the other categories of the typology, for instance, Spearman's interchanges with Cyril Burt (LOVIE & LOVIE, 1993) or accounts of the progression of influences (and reactions to then existing explanations) leading up to Einstein's discovery of the special theory of relativity (STACHEL, 1983).

Yet, these caveats notwithstanding, we propose that it is possible and useful to use our typology to identify and classify particular creative research accomplishments, in other words, scientific achievements that, through their novelty, unexpectedness, or value, have major effects on the theories, methods, and approaches of successive research. Multiple scientists may have been involved in a particular creative accomplishment, although in most cases it is possible to disentangle who did what (albeit not always without controversy).[5] Of course, confirmation of creative research is more readily possible with hindsight, such that claims can be validated (or otherwise) and importance realized. In the next section, we discuss an empirical test of the typology, where expert respondents are asked to identify highly creative research accomplishments in their field over the past decade. The results indicate that our typology is effective and that expert respondents are readily able to use the typology to classify specific accomplishments.

Methodology of capturing creative research accomplishments

The broader aim of our research is to identify creative research accomplishments in particular fields of science as a basis for subsequent examination of the organizational and institutional factors that underpinned those accomplishments. The typology of creative scientific accomplishments presented in the preceding section is one of the tools we use, as part of an international survey of experts in our fields of interest. We combine the results of this survey with data on scientific prize winners in these fields. We believe that this combination allows a better empirical approximation of research

[5] One example is the debate about the role of Rosalind Franklin in the discovery of the structure of DNA in 1953. For many years, James Watson, Francis Crick, and Maurice Wilkins were credited with this discovery, and the critical scientific work contributed by Franklin was obscured and disregarded. Since the 1970s, and particularly more recently, there has been increased attention to Franklin's creative research contribution (see, for example, MADDOX, 2003) in discovering DNA, although Watson and Crick still remain the scientists most popularly associated with this accomplishment.

creativity as a latent variable than either citation analysis or expert opinion surveys alone. Here is an overview of our methodological approach.

1. To develop a database of experts in our two research fields of nano S&T and human genetics, we used bibliometric search strategies to identify individuals who have published in these fields. In nano S&T, we are aware that there are several dedicated nanotechnology journals, such as the *Journal of Nanoparticle Research*, *Nano Letters* or *IEEE Transactions on Nanobioscience*. However, authors in nanotechnology also publish in various other disciplinary journals such as *Physical Review Letters*, *Surface Science*, or *Advanced Materials*. Moreover, because of the heterogeneous nature of publication in this emerging field, publication databases such as the Science Citation Index (SCI)[6] do not offer a single field definition or subject category that can be applied. Hence, we used a search term strategy for nanoscience and nanotechnology that consists of field related keywords. This search term strategy has been successfully applied in a number of other nano S&T studies (NOYONS et al., 2003; HEINZE, 2004; 2006). Genetics is an established area of scientific research, and consequently the SCI provides a journal-based delineation of the field including journals such as *Advances in Human Genetics*, *Annual Review of Genetics* or *Chromosome Research*. However, our focus is on human genetics as a subfield of the broader research area. Hence, in addition to the journal set we rely on keywords developed by LAREDO (1999) and keywords provided by experts in our home institutions in fields related to human genetics.
2. Our search strategies selected all publications matching the search terms for the time period 1995–2004 in the SCI. The ten year time window was chosen for two reasons. First, our broader study focuses on current creative researchers and groups. We do not examine research creativity from a historical perspective. Second, a period of multiple-years is necessary in order to identify a substantial number of authors and to capture variations, both with respect to researchers and institutions. A search period of ten years reasonably accomplishes both objectives.
3. Datamining software[7] is used to clean, organize, and analyse the publication data in the two fields of Nano S&T and Human Genetics. This enabled us to identify experts currently based in Europe or the United States by affiliation in academia, government labs, industry and other organizations. We also distinguished between highly-cited researchers and active publishing

[6] Science Citation Index (SCI), available through the Web of Science, Thomson Scientific.
[7] We used VantagePoint, a data- and knowledge-mining software developed by Search Technology in association with the Georgia Tech Technology Policy and Assessment Center, see: http://www.thevantagepoint.com/

researchers. For a sample of these experts, we double-checked and updated current affiliations, addresses, and email information using on-line searches.

4. On-line searches and expert consultations were undertaken to identify journal editors, program managers and funding gatekeepers in the two fields currently based in Europe or the United States.
5. A nomination survey was designed, piloted, and implemented. The survey was administered to five target groups (highly-cited researchers, active university and government laboratory researchers, active industry researchers, program managers/funding gatekeepers, and journal editors) in the two fields in Europe and the United States. The survey asked respondents to nominate up to three creative research accomplishments in their field published since 1995. Respondents were requested to indicate why they judged nominated research as creative by providing them with the typology of creative research accomplishments presented in the previous sections. Respondents were also asked to identify major prizes and journals in their field and to provide some additional information about their own area of expertise. Nominations of creative research received through the nomination survey process were checked and validated (for example, spelling of names of nominated creative researchers and current affiliation and address).
6. On-line searches and expert consultations were undertaken to identify a list of appropriate scientific and research prizes in the two fields awarded by European and US organizations. Major professional societies in Europe and the United States were screened for relevant prizes, for instance, the Royal Society, the Royal Swedish Academy of Sciences, the European Society for Human Genetics, the Deutsche Physikalische Gesellschaft, the Société Francaise de Chimie, the American Physical Society (APS) or the Materials Research Society (MRS). Furthermore, major funding bodies and research organizations were examined, such as the Deutsche Forschungsgemeinschaft, the Max-Planck-Gesellschaft, the Centre National de Recherche Scientifique, the Philipp Morris Foundation, and the National Science Foundation (USA).

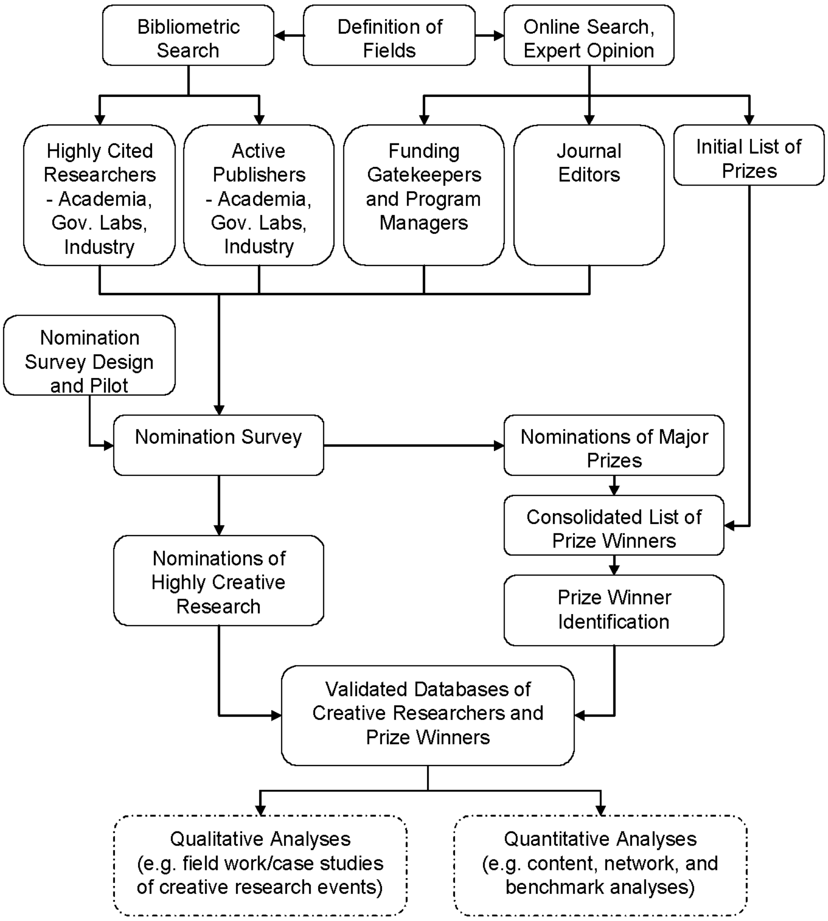

Figure 1. Methodological steps to identify creative research in nano s&t and human genetics
Note: Dotted-line boxes describe steps in subsequent stages of the CREA project
(not discussed in this article).

7. Respondent nominations of major prizes in the two fields were consolidated with the initial lists of appropriate prizes, to build a consolidate list of prizes. Winners of these prizes were identified and validated, resulting in a validated list of prize winners currently based in Europe and the United States in the two fields.

The steps of this methodology are illustrated in Figure 1. As a result of this process, we built two validated databases: one for creative research nominations and another one for prize winners in the fields of nano S&T and human genetics (both Europe and the

United States). These databases were then analysed. We used content analysis to retrieve aggregate information on topics and subfields that constitute areas of current creative accomplishments in the two fields. The two databases were also used to distinguish between various categories of creative scientists. The following section describes the results of these analyses in some depth. Additionally, these databases will be used to select particular creative research events that will be the focus of case studies and in-depth field work (work-in-progress, not described in this article).

Empirical results

Nomination survey expert panel

Building on the bibliometric field delineations discussed above, we identified a stratified group of knowledgeable experts in the fields of nano S&T and human genetics who could offer nominations as to creative research accomplishments. We sought to ensure that a variety of experts associated with a range of organizations and perspectives in Europe and the United States would be polled. The panel was asked to nominate highly creative research accomplishments in their respective fields.

Our stratification method identified researchers in five target groups. First, highly-cited first authors of publications were identified in the two publication datasets (nano S&T and human genetics). This selection was based on the total number of citations an author received in publications in the field-specific datasets between 1995 and 2004. We anticipated that these recognized researchers would be primarily academics and that they would have in-depth knowledge of their field. Authors selected by this procedure are on average more senior because they have had more time to accumulate citations than junior scientists, who may have started publishing later in our time window. We therefore identified another set of experts, comprising active publishing researchers with a total number of publications roughly around the median of the entire list of first authors. Within this set, we distinguished between researchers based in universities and government laboratories and those based in industry. We identified these two categories to ensure diversity among the expert panel, for example to include academics and industry researchers who would be able to contribute knowledgeably, who have published in the field, and who might be younger, but as yet might not have accrued highly-cited articles. We anticipated that these two categories of experts might offer different perspectives on creative research accomplishments.

In addition, editors of research journals relevant to the two research fields were identified. Editors have a broad view over their respective field or subfield, are recognized experts in their own right, and are well placed to distinguish creative research contributions, even if not published in their own journal. Finally, research program managers and funding gatekeepers in public bodies such as ministries, research councils or science foundations were selected. These managers and gatekeepers usually have scientific and research backgrounds, have a broad view over their field and detailed knowledge of research activities funded by their organization and others, and also interact with many scientists. These categories of respondents were identified through online searches and a review of editorships of journals.

Combining all the respondent categories together, our target response goal was to achieve 100 completed nomination surveys for each of the two fields, approximately balanced between European and US respondents, for a total targeted response of 200 completed nomination surveys. Within each field, we further set sub-targets of completed survey nominations from 40 highly-cited researchers, 20 active academic publishers, 10 active industry publishers, 15 journal editors, and 15 program managers, again approximately balanced between Europe and the US. We developed samples in excess of these target numbers, anticipating that response rates would be partial.

Nomination survey response

The nomination survey was administered using a combination of contact methods (postal mail and email follow-up), with respondents able to reply by postal mail, email, or via an online survey web site. The survey was conducted between June and September 2005. In total, 185 successful nomination survey responses were received in both fields; of these, 103 were from Europe and 83 from the United States. In nano S&T, 140 responses were achieved. This exceeded our target goal of 100 (Table 2). However, we fell short of our target survey response goal in human genetics. In total, we received 45 successful nomination survey responses in human genetics (compared with our target of 100). In nano S&T, we contacted 313 experts in Europe and 297 in the United States, and achieved response rates of 26 per cent and 20 percent respectively. In human genetics, we contacted 281 experts in Europe and received a response rate of 7 percent. For the United States, the survey was administered to 287 contacts and an 8 percent response rate was achieved. While we are satisfied with the number of responses in nano S&T, we had to accept a lower than targeted response for human genetics. Nonetheless, in both fields, the quality of available responses is generally high. Respondents usually offered multiple nominations, and in many cases added valuable details.

The nomination survey asked respondents to nominate up to three creative research accomplishments in their field published since 1995. The survey asked respondents to indicate why they judged nominated research as creative. Respondents were also asked to identify major prizes and journals in their field and to provide some additional information about their own area of expertise (see Appendix).

Table 2. Nomination survey sample and responses

Category of expertise	Per field			Responses	
	Target	Expected response rate	Anticipated sample (rounded)	Nano S&T	Human genetics
Highly cited researchers	40	15%	270	55	18
Active academia	20	15%	130	31	15
Active industry	10	15%	70	19	2
Journal editors	15	30%	50	18	4
Program managers	15	40%	40	17	6
TOTAL	100	18%	560	140	45

Source: CREA nomination survey, 2005.

Table 3. Region and field of creative research nominees, by region of nominator

Nominators based in	Nominations by field and region of nominated researcher							
	Nano S&T nominees				Human genetics nominees			
	Europe	US	Other	All	Europe	US	Other	All
Europe	99	83	7	189	35	24	0	59
United States	18	101	1	120	3	39	1	43
Total	117	184	8	309	38	63	1	102

Source: CREA survey, 2005. Respondents could make more than one nomination. Total nominations = 411.

Every survey nomination that was submitted to us by experts in Europe and the United States subsequently went through a validation process to confirm name spellings of nominated researchers, current affiliations, addresses, publication dates, and other details. Finally, we recorded more than 400 creative research nominations: nearly 300 in nano S&T and about 100 in human genetics (Table 3). By region, 160 nominations were put forward for researchers currently located in Europe, while there were nearly 250 nominations of researchers currently located in the United States. On average, each survey response produced 2.2 nominations.

Survey results

Creative research nominations by region. There was a noticeable asymmetry in transatlantic cross-nominations (Table 3). For example, in nano S&T, European nominators provided nominations for 99 European-based researchers and 83 US-based researchers; US nominators provided nominations for 101 US-based researchers and for 18 European-based researchers. A similar pattern in transatlantic cross-nominations was seen for human genetics, where Europeans nominated many more US-based researchers than US-based researcher nominations of Europeans.

We found a broad distribution in terms of the creativity types that nominators used to justify their nominations. Nominators could suggest that more than one creativity type described a particular creative research nomination, and many did so. In nano

S&T, respondents in both Europe and the United States tended to nominate creative research that developed new methodology and formulated new ideas or advanced theoretical concepts. In human genetics, European nominators nominated more research contributions that they reported to have formulated new ideas and advanced theoretical concepts, whereas US nominators equally emphasized the formulation of new ideas and the discovery of new empirical phenomena (Table 4).

Table 4. Creativity type of nominations, by field and region

Creativity type		Field and region of nominator							
		Nano S&T		Human genetics		Nano S&T		Human genetics	
		Europe	US	Europe	US	Europe	US	Europe	US
1	New theoretical concepts	48	81	24	26	22%	22%	35%	24%
2	New empirical discovery	39	69	10	26	18%	19%	15%	24%
3	New methodology	50	81	13	21	23%	22%	19%	20%
4	New instruments	42	50	9	17	19%	14%	13%	16%
5	New synthesis	32	65	8	14	14%	18%	12%	13%
6	Other	11	21	4	3	5%	6%	6%	3%
Total creativity types		222	367	68	107	100%	100%	100%	100%

Source: CREA survey, 2005. Respondents could indicate more than one creativity type per nomination.

Creative research nominations by category of nominator. In nano S&T, highly-cited researchers and journal editors both mentioned the development of new methodology most often in their nominations of highly creative research. Funding gatekeepers most frequently mentioned the formulation of new ideas, while active academic and industry researchers gave equal weight to formulating new ideas and new methods. Yet, other creativity types, such as the invention of new instruments or new syntheses, also received multiple mentions by all nominator categories. The "other" category was indicated only in about 6 percent of nominations in nano S&T. Most of the "other" nominations were provided by industrial researchers and funding gatekeepers. Several nominated researchers for their creative contributions to applied research and technological applications (Table 5).

In human genetics, there was a different pattern. The discovery of new empirical phenomena or relationships was most frequently mentioned by journal editors and funding gatekeepers. Highly cited researchers and, most noticeable, active industry researchers more frequently mentioned the formulation of new ideas and advancing theoretical concepts in their nominations of creative research in human genetics. Even fewer nominations – about 4 percent – were in the "other" category, and there was no convergence within this group.

Table 5. Creativity nominations by category of nominator, (Europe and United States Combined)

Creativity type		Category of nominator					
		Highly cited	Active academia	Active industry	Journal editor	Program manager	Total
Nano S&T (N)		217	162	61	55	84	579
1	New theoretical concepts	24%	22%	16%	18%	26%	22%
2	New empirical discovery	19%	19%	21%	24%	12%	19%
3	New methodology	26%	22%	16%	25%	19%	23%
4	New instruments	11%	17%	11%	18%	17%	14%
5	New synthesis	18%	18%	15%	11%	15%	17%
6	Other	2%	2%	20%	4%	11%	6%
		100%	100%	100%	100%	100%	100%
Human genetics (N)		58	47	31	5	27	168
1	New theoretical concepts	24%	26%	58%	40%	11%	29%
2	New empirical discovery	16%	26%	0%	60%	37%	20%
3	New methodology	19%	19%	13%	0%	33%	20%
4	New instruments	16%	15%	13%	0%	19%	15%
5	New synthesis	19%	11%	16%	0%	0%	13%
6	Other	7%	4%	0%	0%	0%	4%
		100%	100%	100%	100%	100%	100%

Source: CREA Survey, 2005. Respondents could nominate more than one creativity type.

It is plausible to expect a relationship between patterns of creativity types and overall field developments. There is some evidence for this in our results. First, among the major early research breakthroughs in the field of nano S&T was the invention of the scanning tunneling microscope (STM), a powerful research instrument (HESSENBRUCH, 2004). When compared to the whole field of nano S&T, the STM subfield shows much higher publication growth rates in the mid 1980s but decreasing growth rates after 1990. This is reflected in few survey nominations in new instruments only (14%). In contrast, publication growth has increased since the early 1990s in the subfield of carbon nanotubes and fullerenes, as reflected in other creativity nominations, such as new methodology (23%) or new empirical discovery (19%) (Table 5).[8] Second, the field of human genetics was invigorated over the 1990s by the Human Genome Project which yielded enormous amounts of new empirical information about the human genome using highly effective sequencing instruments (FERRY & SULSTON, 2002). Consequently, we find fewer nominations in our survey in categories of new instruments (15%) or empirical discoveries (20%), and more in new theoretical

[8] Data is not documented here, but will be made available on request to the first author.

concepts (29%). In recent years, the major challenge in human genetics has been to link genetic information with diseases, i.e. to construct causal links between single genes or interacting genes and certain kinds of disease phenomena.

Overall, our typology of creative research proved to be a viable classification scheme. In nano S&T, 94 percent of all creative nominations were distributed across the five categories; in human genetics, the equivalent figure was 96 percent. We judge that the classification scheme proved to be robust in this application, although additional empirical trials should be undertaken to see if the scheme holds up as well in other areas of science and perhaps to further probe the category of highly creative applied technology oriented contributions.

Topics and areas of creative research as displayed in nominations. Respondents were asked to describe (in text) the research accomplishments that they nominated as highly creative. In most cases, such descriptions were provided by nominators. As a result, the nomination database contains rich characterizations as to the topics, subfields and qualifications of nominated scientists. Figure 2 shows a comparison of two distributions of the most frequently mentioned terms and word combinations in the field of nano S&T. One distribution stems from our nomination survey database, the other is derived from our nano S&T publication database. The most common terms used in the nominations – molecul* or nanoscal* or atom* – may be viewed as scale modifiers inherent in nano S&T research. However, the next group – lithograph* or electronic* or semiconduc* or conduct* – draws attention to a body of creative nano S&T work in materials science, applied physics, physical chemistry, and electrical and electronic engineering. The third group of terms – bio* or DNA or sensor* or gene* or protein* – suggests a body of creative nano S&T work in biochemistry, molecular biology, and nano-medicine.

Given the findings from Table 5, some converging findings emerge from the comparison with Figure 2. First, nano S&T subfields with higher shares in the nomination survey compared to all nano S&T publications point to poles of creative research, such as *nanoelectronics* (lithography …, transistor…) and *nanomaterials* (material…, carbon…). Secondly, the remarkable difference between the survey and publication database distributions in *carbon nanotubes and fullerenes* (carbon…) triangulates our earlier finding of a considerable dynamic in this area. Thirdly, survey nominations indicate a relatively lower level of cognitive innovation in *nanocharacterisation* (scanning…, propert…) compared to all nano S&T publications. This result corroborates our previous finding that decreasing growth rates in *nanocharacterisation* related publications suggest a smaller cognitive innovation momentum in this area compared to the overall nano S&T publication growth path. Further substantiation and any generalization of these results will require additional research, but the analysis does highlight key areas to probe in terms of the relationship between different types of creativity events and overall field developments.

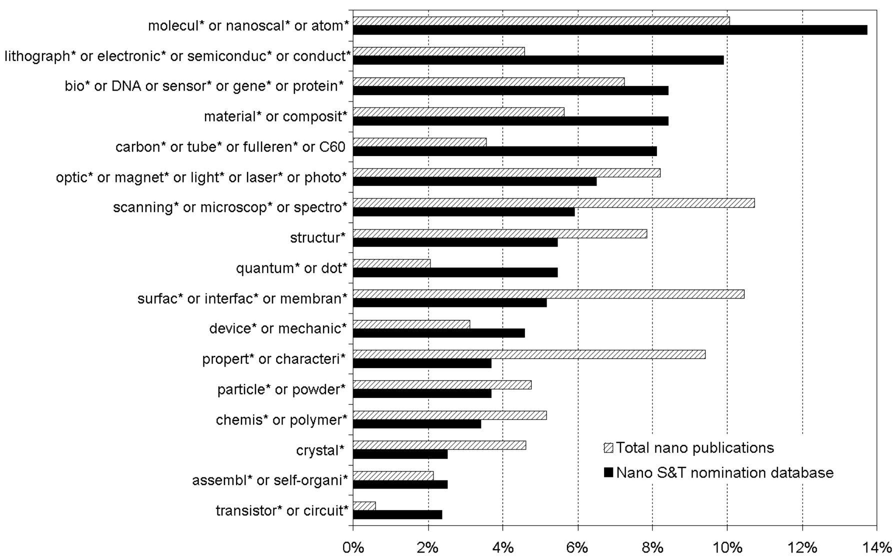

Figure 2. Terms most frequently mentioned in nominations of highly creative research and publications, Nano S&T (percent)
Sources: SCI (host STN); CREA survey, 2005, European and US nominations.
Note: Non-fractional counts have been standardised. Search string categories sum up to 100 per cent.

Prize winner database

In parallel with the nomination survey, we identified relevant prizes in the two fields, drawing on respondent nominations, other expert input, and our own knowledge. On the European side, the search process resulted in a validated list of 43 prizes relevant for nano S&T and 29 prizes relevant for human genetics. For the US, we identified 12 prizes relevant for nano S&T and 7 relevant prizes for human genetics. We also added other relevant international prizes in these fields, including 2 prizes from Canada (in human genetics) and one prize from Japan (open). Several prizes are overlapping, in that they have been be awarded for research in both fields. Additionally, while some prizes are restricted or typically awarded to scientists in the home country, many are open (perhaps most prominently, the Nobel Prize). Hence, US scientists are frequently recognized by European-based prizes and vice-versa.

There are two broad classes of prizes. First, generic scientific prizes that come with a substantial amount of research money. For example, the German Leibniz Prize or the Dutch Spinoza Prize are each endowed with 1.5 Million. Among the highly endowed prizes, some are dedicated to supporting promising junior researchers, such as the

European Young Investigator Award of the European Commission (1.25 Mio.) or the Young Researchers' Award in Nanotechnology of the German Ministry of Education and Research (up to 2.5 Mio). Second, there are highly prestigious prizes, primarily from the learned societies, which provide only small amounts of money. Examples are the Schottky Prize of the Deutsche Physikalische Gesellschaft (15.000), the Copley Medal (£ 5.000) and the Hughes Medal (£ 1.000) of the Royal Society.

In nano S&T, relevant prizes identified include: the Agilent Prize, the Buckley Prize, the Burton Medal, the CNRS Gold Medal, the Copley Medal, the Feynman Prize, the Gustafsson Prize, the Hahn Medal, the Italgas Prize, the Krupp Förderpreis, the Leibniz Prize, the Materials Research Society Medal, the Max-Planck Research Award, the Morris Prize, the Nobel Prize, the Schottky Prize, and the Spinoza Prize. It should be noted that few prizes are specifically dedicated to nano S&T, an exception being the Foresight Institute Feynman Prizes in Nanotechnology. More frequently, prizes are associated with a discipline (such as physics or materials research) or an organization (such Max-Planck or CNRS) and awarded to nano S&T researchers. Our approach was thus to identify relevant prizes broadly, then to carefully review all awards and laudations to explicitly identify nano S&T research and associated prizewinners. Our search period was 1995–2004. In total, 150 entries are in the European nano S&T prize winner database, which are distributed across 139 scientists. The US nano S&T prize winner database has 114 entries distributed across 108 scientists.

In human genetics, relevant prizes included: the American Society of Human Genetics Allan Award, the Asturias Award, the Balfour Lecturer Award, the Baschirotto Award, the Bickel Award, the Biofutur Prize, the Jeantet Prize, the EMBO Medal, the European Society of Human Genetics Award, the Gairdner International Award, the Genetics Society of America Morgan Medal, the Gruber Foundation Genetics Award, the Gustafsson Prize, the Heinz-Maier-Leibnitz Prize, the Körber Award, the Lasker Award, the Leibniz Prize, the Max-Planck Research Award, the National Medal of Science, the Nobel Prize, and the Spinoza Prize. While there are several dedicated prizes for human genetics, again there are a number of other relevant prizes. We used the same methodology for nano S&T, namely to identify relevant prizes broadly, then to carefully review all awards and laudations to explicitly identify human genetics research and associated prizewinners. For the 1995-2004 period, there are 134 entries in the European human genetics prize winner database, distributed across 121 scientists. For the US human genetics prize winner database, there are 53 entries distributed across 52 scientists.

Synthesis of nomination and prize winner data

The previous sections have separately discussed how the nomination and prize winner data were assembled, together with selected results for each source. We now turn to present a synthesis of the two data sets. We merged the nomination and prize winner data so as to offer a consolidated basis for studying creative research accomplishments. After completing this data merge, we probed the extent to which the survey nominations and prize winner data are complementary in identifying creative scientists. We are able to identify scientists with multiple survey nominations, multiple prize awards, and multiple combinations of survey nominations and prize awards, as well as those with single nominations and single prize awards. We are particularly interested in scientists with multiple nominations, since recognition of their creativity is derived from more than one source. Table 6 shows the four multiple categories of scientists that are derived from connecting the two databases.

Table 6. Distribution of creative scientists, combining nominations and prize winners

	Nano S&T		Human genetics	
	Europe	US	Europe	US
Multiple prize winners	9	5	10	1
Multiple nominations	7	21	0	3
Prize winner and nomination	16	17	5	9
Multiple prize winners and multiple nominations	3	4	0	0
Total highly creative scientists	22	29	14	11
Total scientists in database	224	204	150	111

Source: CREA database, 2005. Due to overlap between categories, the total of highly creative scientists is lower than their sum.

An analysis of scientists with multiple entries shows that there are differences in the level of convergence within the datasets. While there are 7 (out of 224) scientists in European nano S&T, who have been nominated more than once, there are none (out of 150) in European human genetics. In the US, there are 21 (out of 204) scientists in nano S&T who were nominated more than once and 3 (out of 111) in human genetics. There are broadly similar numbers of multiple prize winners in nano S&T in Europe and the US, but there is an asymmetry in multiple prize winners in human genetics, with 10 identified in Europe and 1 in the US (Table 6). The database of European human genetics nominees is relatively small, in part because of lower response and in part because European human genetics respondents gave two-fifths of their nominations to US-based scientists. This may have led to fewer chances for convergent judgments in nominations. Conversely, there were many more prizes relevant to human genetics identified in European countries and at the trans-European level (29 prizes) than in the US (7). So, this may – at least in part – explain the relatively higher number of multiple prize winners in human genetics in Europe.

We judge that combining the nomination and prize winner data is a complementary way of addressing some of these methodological issues, at least for the larger purpose of our project where the identification of creative research accomplishments is a means rather than an end in and of itself. Complementarity means that the combination of two data sources provides richer information than single source data. We can gauge complementarity by counting the number of scientists that are added on top of multiple prize winners or multiple nominations. For example, in the case of European nano S&T, there are 16 researchers who received both prizes and nominations, of which 3 received multiple prizes and multiple nominations. Comparable numbers (17 and 4 respectively) are found for the US. (Table 6). While the convergence criterion (either nomination or prize winner data) appears as a useful predictor of research creativity, the combination of data sources adds more variance to the sample.

Converging nomination and prize winner data raises the question of whether researchers in the third and fourth categories – scientists who have won both prizes and received nominations and who might be regarded as at the apex of the set – are different from other researchers in our sample (Table 6). We cannot judge this in detail yet, because we have yet to complete the in-depth interview and field-work phase of our research. However, in terms of creativity types, researchers of the third and fourth category and in the field of nano S&T tend to have accomplished more theoretical work, as captured by the first creativity category: Formulation of new ideas, advancing theoretical concepts.

Summary and discussion

There is both the opportunity and the need within science studies and the science and technology policy field to undertake further research on scientific creativity so as to better understand the organizational and institutional factors that underpin creative research accomplishments. But an important precursor to such research is to address problems of how creative research can be defined and how it can be identified empirically. In addressing these problems, this paper has reviewed some of the major ways in which creative research has been defined to date and, building on insights from this work, has proposed a functional typology of creative research accomplishments. The paper has also described the methods and results of an exercise which builds on this typology to identify creative research accomplishments and scientists in the fields of nano S&T and human genetics in Europe and the United States. This effort combines nominations of creative research obtained through international survey of field experts with data on scientific prize winners in these fields.

Several summary insights can be drawn from this work. First, we suggest that our functional typology is a constructive and practical schema for classifying creative research. Conceptually, it allows distinctions to be drawn among the range of ways through which creative scientific research can be expressed, be it driven by new theory, methods, instrumentation, observation, or synthesis. Empirically, we have demonstrated that the typology can be used effectively by experts in the field and captures almost all of the creative research nominations offered in the two scientific fields of nano S&T and human genetics.

Second, our results confirm that research regarded as highly creative has a multi-dimensional distribution. Creative research it is not always about the formulation of new theoretical ideas, but can involve the development of new methods or instruments or be stimulated by empirical observation or synthesis. Moreover, the pattern of creative research accomplishments varies by field, stage of scientific development, and variations in science systems, as illustrated by the contrasts we found in nominations of creative research by type in nano S&T and human genetics and between Europe and the US.

Third, we found that combining our two data sources – the nominations of creative research and the databases of scientific prizewinners – was complementary and offered additional validation, particularly in identifying researchers who were recognized for their creativity through multiple nominations and prizes. This combination, incorporating the judgments of numerous experts, provides a foundation for the further identification of subjects and topics for additional case study and field research.

We accept that this is still early work and that there are a number of avenues which have yet to be explored. One is to examine the relationships between nominated creative researchers (obtained through our expert survey and prize winner data bases) and bibliometric assessments of highly cited researchers. We would anticipate a measure of overlap, but we would also expect some differences. The composition of the interstices would be particularly interesting to explore and understand. A second avenue would be to analyse in more detail how highly recognized creative researchers (i.e. with multiple nominations and prizes) differ from recognized creative researchers (single nominations) and non-recognized researchers in the same field. This would be particularly interesting to the extent that factors such as age or years in the field were controlled. Finally, it would be useful to further test our creative research typology and early results by extending studies into other fields of science.

*

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Appendix
Extract from survey questionnaire

Please provide your nominations for up to three highly creative research accomplishments in Nano S&T (Human Genetics) published since 1995.

Highly Creative Research Accomplishment in Nano S&T – Nomination 1	
Name of researcher or research group*	
*Name of research leader, if a group	
Principal institution of research leader or group	City Country
Brief description of research accomplishment	Year first published (approx.)………...
Reason why this research is justified as highly creative	Use justification number (see below) or write in other justification

Possible reasons justifying research as highly creative
1. Formulation of new ideas, advancing theoretical concepts
2. Discovery of new empirical phenomena or relationships
3. Development of a new methodology, allowing new empirical tests of theories
4. Invention of new instruments, opening up new research possibilities
5. New synthesis of existing or dispersed ideas
6. Other – please write in reason