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Forces and functions in scientific communication: an analysis of their interplay

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Dans la vie, il n'y a pas de solutions.
Il y a des forces en marche: il faut les créer et les solutions suivent. *
(Vol de nuit, Antoine de Saint-Exupéry, Ch. 19)

Abstract:

This article analyses the transformation of the familiar, linear scientific information chain into an interactive scientific communication network in response to concomitant changes in scientific research and education. Societal conditions are seen to lead to the concept of strategic research world-wide: research dominated by "economy of scope". Strategic research leads to transnational research enterprises - universities and other research institutions-with a focus on return of research capital investment, and thus on intellectual capital. This development calls for new ways of knowledge management that in turn has consequences for scientific communication.
The scientific communication market is described in terms of four main forces and their interplay. These forces are the actor pair (author/reader), accessibility, content, and applicability. Scientific communication is described in terms of its four functions: registration, awareness, certification and archive.
These forces and functions allow a strategic analysis of the scientific communication market and allow to discuss aspects of strategic correspondence to be applicable in e.g. describing the transformation from a paper-based system to communication in an electronic environment. The developments in research are seen to emphasize the already existing autonomous development of a "unified archive", lead us to review certification policies to include elements external to research and lead us to consider new structures for communication, and publications. The new structures are a result of the interactions in the market as described through the forces and the functions. The distinction between formal and informal communication is seen to become less useful. The need to review the structure and organization of the market becomes evident, in particular if we consider communication during research as well. This leads us to speculate if elements of the virtual organization are of relevance. Finally, the need for a coherent research programme on scientific

communication is discussed.

1. Introduction

It is generally understood that we are at present experiencing a transformation in the familiar scientific information chain, i.e. from author to publisher to library to reader.

In this article we will analyse this transformation. We take the view that this transformation is of a strategic nature rather than primarily driven by technology forces: the linear information chain is being fundamentally transformed into an interactive communication network as this is required to support the present, societal demands for knowledge growth and management.

A starting point is that our current policies and practices in science and communication are not ideal for an optimal exchange and refinement of our knowledge (1) while this is more than needed in our present, knowledge intensive society. To this end we need to study the role of publications in science. These publications are at present the main carriers for a heterogeneous exchange of knowledge which is seminal to the progress of science.

However, we should not stop at this point. If we acknowledge that the above points are of relevance then we should also look at possible configurations for communication (2) as communication can only be effective and efficient, and this is the key issue, if its configuration appeals to the research community, also in its relation to society at large. Also differences in configurations between disciplines need to be studied, as these differences should not impede knowledge transfer in transdisciplinary or interdisciplinary research. We need to address the role of communication and its organization in relation to the entire research process.

This leads us to the issue of complexity and above all the seeming abundance of scientific information. It has often been stated and is still stated that the nowadays-excessive rate of production of original scientific work cannot in the end but retard scientific progress, as there is no time anymore for the proper aging of theories (3). And indeed we seem to suffer from abundance, rather than from a scarcity of information and data.

It may be evident that the cure to the above mentioned symptoms is not to slow down scientific research and education. It rather shows quite convincingly that we need new methods of scientific communication that will greatly speed up the advancement of science. Research time to explore the abundance of information and data seems the main issue and is the focus for improving the effectiveness and efficiency of the scientific communication system.

These arguments seem sufficient to envision a strategic - or structural - transformation to a scientific communication network as opposed to a more tactical -or mechanical- transformation of the information chain that can only result in just an improvement of the existing system.
Technology serves as an important driving force as it enables further developments in the research process: above all, technology empowers researchers to induce a structural change in their communication configuration, and if this change can lead to improve the advancement of knowledge, this opportunity will be seized.

In consequence, it may well lead to structural changes in the way the science process is perceived as its communication reflects to a high degree most relevant aspects of this process. E.g. the arrangement of the experimental article re-enacts the process of induction. A modular approach to a scientific article as is being investigated (4) may then well lead to very important consequences in the research process.

We will analyse the thesis that the transformation is of a structural nature. We will analyse a number of aspects of scientific communication, its relation to scientific information on the one hand side, but above all its relation to the science process, its goals and its stakeholders and how this process relates to actual societal demands.

This approach necessitates an analysis of the main constituents of scientific communication and its dynamics. Furthermore we will define a set of main functions to be performed in scientific communication rather than analyzing needs related to scientific information.

A main reason to choose for a functional description is that it represents a more mature methodological approach. As functions are defined as intrinsically invariant - or otherwise stated independent of changes in parameters such as information technology - these functions are a main cause of correspondence, or continuity, and allow in this way to analyse in an independent way chances and opportunities that information technology presently offers for scientific communication.

This property of correspondence is important as some discussions on the transformation of the information chain refer to an information crisis (5) and conflict between the stakeholders in the information chain. This leads to a dialogue between the stakeholders but this dialogue has not proven to lead to structural solutions.
A functional approach on the contrary allows investigating and discussing aspects of correspondence. It addresses the balance in the market rather than focusing on the "overproduction" of information.

Such a methodological functional approach is most relevant if the transformation to a communication network is a structural one. Thus it also represents a critical selfconsistency test for this functional approach.

In the next section we will discuss the environmental conditions driving this transformation; section 3 will discuss the consequences for scientific communication; section 4 will analyse in detail the main forces and functions of scientific communication and section 5 will finally describe the strategic consequences for the stakeholders, such as a future structure and organization within the overall science process.

2. Societal Trends

2.1 General

Over the last decades we have noted a firm trend in society to become more and more demanding with respect to science (see e.g.:6-9). The ending of the Cold War, which with regards to science lead to a severe reduction of research programmes has accelerated this trend, in particular those related to the arms industry. Quite paradoxically these research programmes were based on research philosophies that came very close to the notion that academic research will eventually lead to spin-offs that are relevant to society at large. And indeed, research did deliver as can be witnessed by the extremely fast development of e.g. semiconductor research leading to the rapid deployment of computer technology or, as another example, the development of nuclear research oriented instrumentation contributing to the development of our present day medical instrumentation, e.g. in cancer theory and scanning techniques.

However, there are also examples where the "return on scientific capital" is less satisfactory, such as

e.g. the nuclear fusion reactor or space research. Despite a somewhat slow start, solar energy technology now comes to fruition and lives up to its promises. These examples are taken from the exact sciences. The general observation is equally valid for the social and behavioral sciences.

Nevertheless, society - and therefore industry - are continuously upgrading their demands on "return of scientific capital". The turnaround time of scientific research is the parameter used. Its orientation on the market, i.e. the demand for direct applicability of its results, has become stronger and the more limited funds for research, both public and industrial funds, have lead to a stronger focus on the scope of research to be funded.
One could say that we are witnessing a gradual change in research over the last decades from a general philosophy that can be described by "economy of scale" in research, characterized by "unlimited" research resources, to an "economy of scope", characterized by scarcity in research resources leading to selectivity along societal priorities, and demanding research breakthroughs within an acceptable time horizon.

As a corollary we witness even tighter planning of research at large and the development of "strategic research". Strategic research means the active planning of entire research programmes and represents a firm trend towards what can be called an "a priori" mode or conceptual attitude towards research discoveries (10). This as opposed to a more "tactical" or "a posteriori" attitude practised after the Second World War till the eighties.

Strategic research has to fulfill societal demands in combination with research initiatives driven by curiosity.

Aspects of strategic research and its consequences are discussed below. Its development itself is further pushed by the fact that intellectual capital is considered to be the "main engine for (industrial) development rather than monetary capital, natural resources, or even more traditionally land" (11).

Thus "scientific capital" leads to strategic research which in turn leads to more "a priori" planning of research programmes, including the societal implementation of its research results.
This development seems somewhat paradoxical as it is generally held that the Cold War was won by the Western world because of its rapid technological development that could not be met by the communist world. However, as we have seen, the West had a more tactical attitude seeing applied research as a spin-off of wider academic research programmes, whereas the East had introduced strict planning, albeit ideological planning, of research already a long time ago.

2.2. ’Strategic Research’

The trend to strategic research can be witnessed in the research policies of the industry world-wide. Many industrial companies have been or are reorganizing their research policies towards more economy of scope, sometimes even resulting in a (partial) divestment of their research laboratories.

But also national governments world-wide and supranational bodies have continued and strengthened a fundamental reorganization of their higher education programmes and are influencing the research programmes of the universities and their countries by their funding strategies.

In order to introduce "strategic research" governments attempt to establish recognized national "centers of excellence" within a specific research programme. In this way an institutionalized accountability for entire research programmes is introduced on top of the accountability of the

individual researcher for his research efforts as usually reported in the researcher's individual publications.

Academic research has always been international, at least in a large number of more fundamental research disciplines such as mathematics, physics, chemistry, materials science etc., but the above developments at universities and other research institutes add a new component to the trend towards international or rather transnational or global research entities. One of the consequences of strategic research is that universities and research institutions are developing into transnational research corporations with a strong market orientation and as a consequence a long term focus on research combined with a shorter focus on management. Pharmaceutical research is a good example of research with a strong societal component and a strong link to industry. Strategic research means stronger planning of entire research programmes in a "a priori" mode with a shorter research-planning horizon. Finally, it will lead to transnational integrated research enterprises (such as e.g. CERN). This will in turn reduce the control of national governments on these institutions.

We have discussed the consequences of research, but it goes without saying that the above mentioned developments have also important consequences for the educational tasks of the universities and other institutes of higher education. Curricula need to be trimmed towards the new research philosophy, and are generally shortened and at the same time more focused. As a consequence people are less educated in the "academic" way but more trained to apply their knowledge directly on the short term. As a result the demand for re-education or continuous education becomes stronger (see also 8, 9) which adds to the revenue stream of these institutes for higher education.

These developments lead to important managerial changes for universities and research institutes. We have seen that universities develop into transnational or global networks of centers of excellence in a highly competitive world. In short, the core competencies of these centers of excellence are problem finding and solving, verification and falsification, and the "economic" elements (12) scarcity, preference, opportunities leading to innovation, cost, choice and competition. Cost stands for the usual cost factors such as money, time, foregone benefits, and psychological and political costs. These are the main instruments that are needed to manage the university enterprise. This represents a shift away from a primarily "curiosity driven" university. In essence we witness a shift in the balance between supply and demand: societal demands translate into conditions for research.

The main scarcity is no doubt intellectual or scientific capital, and as a derivative internal research time. As a consequence, knowledge is the main engine for the institution's revenue stream. This knowledge must be scrupulously managed, and matched to societal and industrial demands, and indeed we now see the development of a new discipline in its own right: knowledge management. Its main beneficiaries will be the universities and other research institutions that are in need to explore their precious scientific capital.

It has often been stated (13) that it is much more difficult to see a problem than to find a solution for it. And indeed, it is the most tedious task of research management to see the right problems to be addressed in the above sketched, new competitive environment of strategic research.

2.3 Some methodological aspects of 'strategic research'

Following Lakatos (14, 15) the problems chosen in powerful research programmes are determined by the heuristics of the programme, i.e. the research questions and methodology. A programme has positive heuristics when it produces higher order research questions.

Lakatos concludes that his methodology of scientific research programmes accounts largely for the relative autonomy of ’theoretical science’. And undoubtedly, such autonomy has lead to the positive development of the scientific enterprise, as we know it at present.
It is obvious that within these definitions positive heuristics are based on a definition internal to research. However, the development of our universities into transnational centers of excellence requires not only internal heuristics for the research programmes but demand some sort of external heuristics as well. The origin for these heuristics rests in the applicability of the research results for societal purposes.

A task for strategic research is to translate such external heuristics into internal heuristics that can provide a solid basis for the research accountability of both the institution and the individual researcher. Care must be taken to avoid a conflict between external and internal heuristics, as this would easily turn a research programme into a degenerating phase.

It has been observed (1) that "knowledge growth has been most robust and resilient when scientific communication and the freedom they entail are openly respected and encouraged", and indeed this has served the progress of science very well. Scientific knowledge seems "to evolve in a spontaneous order and achieves progress by abandoning problem solutions that are less good than the competition" (12). However, in strategic research there may be other, more economic reasons rather than methodological to settle a competitive dispute of research in relation to society.

This analysis shows that there are some complex cultural aspects inherent to strategic research. We have observed that the knowledge industry at large (universities, research institutions, industry, etc.) requires, because of its entrepreneurial orientation dictated by the "economy of scope" or "centers of excellence", a novel approach to knowledge management.

An important issue is to identify and develop a new "normative culture" of strategic research. It may be evident that this is a key issue for the future development of scientific communication. Our present system of research publications as a formal part of scientific communication is firmly based on the existence of a well-defined normative culture (16).

Thus within the broader realm of scientific communication the question: "are research publications in a degenerating phase of the communication programme?" is a very legitimate one.

In order to address this question we will use a methodology based on analyzing scientific communication in its main forces and functions and how these will develop under changing environmental conditions.

2.4 Concluding remarks

Societal demands have lead to the development of "strategic research" in response to the need to develop "economy of scope" within research. The universities and other research institutions develop into transnational strategic research enterprises, into "centers of excellence". Intellectual capital is the main engine of progress of this knowledge industry and knowledge management is developing into a strategic research discipline in its own right.
Strategic research requires its own methodology and this has far reaching consequences for scientific communication that is needed to support strategic research. A particular aspect is the proper evaluation of research within this new context. The suitability of the present instrumentation of scientific communication is being questioned.

3. Consequences for scientific communication and choice for a methodology

Scientific communication serves to boost the progress of (strategic) research. Its objective is growth of knowledge by improving the effectiveness and efficiency of research and as such it incorporates some intriguing aspects of metascience: how can we reconciliate such seemingly opposing conditions as careful planning of research programmes and spontaneous evolution of research? As already stated above a solution needs to be found in matching external and internal heuristics.

Next to the advancement of knowledge scientific communication is most relevant to proper knowledge management: how can it support strategic research in evaluating its results and the institutions and individuals who generate these results? How can we define the competitive environment? It should provide a proper "measure" taking into account the development as sketched under the present conditions of steady state science (17, 18) and at the same time finding within strategic research a proper balance between programmes of basic and applied nature.
We have seen that the issue is not only to solve the research problems at hand but also above all to find the research problem of relevance. The effectivity and efficiency of scientific communication is determined by its combined ability in facilitating both the generation of relevant research problems (or raising the right questions) and the solution of these problems (or giving the right answers). This also relates to the issue of use, availability and retrievability of information. Just to mention an example: information (or data for that matter) is not anymore an element of scarcity. Rather research time (and money) to explore the abundance of information is the main element of scarcity.
The added value is not anymore in information proper but in its effective and efficient communication, or knowledge management.
Inherent to the concept of strategic research this makes scientific communication a strategic issue, both at the research institutional level and for the individual researcher.
It is therefore subject to the same economic elements that were mentioned before. Just as for research itself economic rationale will have, to a certain extent, priority over methodological scrutiny, but without sacrificing methodological scrutiny.

Just as societal conditions have been seen to translate into research conditions, strategic research conditions translate into conditions for scientific communication.
Thus strategic research will represent a new balance between the three classical questions that we seek answers for (19): what range of problems is worth investigating, how is this range to be investigated, and what do the results of these investigations mean?
It may be evident that the strategic research developments impact on all answers to these questions. The societal interaction will determine these answers to a larger degree.
We realize that this is not new. It is well known that in the seventeenth century Huygens devoted a major part of his scientific life to investigating vibrations and pendula (20). While this lead to a series of very fundamental observations, Huygens research programme was evidently driven by the need for highly reliable ship clocks in all naval countries, and in particular in The Netherlands.

One of the main criticisms on present day research is that it leads to a redundancy in research efforts. Certainly one of the main objectives of strategic research is to reduce redundancy by better planning of (transnational) research programmes. On the other hand, as Merton (16) has already shown, we should not see multiple or repeated discoveries as an inefficiency of the research system but rather as an indicator for the maturity of such a discovery.

We need to make a clear distinction between genuine multiple discoveries and inefficient research

and communication. And indeed, one of the main criteria for an effective and efficient scientific communication system is that it reduces redundancy and increases the rate of detection of genuine multiples. This is even more important in a strategic research environment. Also, redundancy should not be confused with obsolescence. Especially in higher codified scientific disciplines, such as e.g. High Energy Physics, the rate of obsolescence of research results, and thus publications is rather high. This reflects the rapid progress in these disciplines, and obsolescence is a natural, rational characteristic (16).

The question then arises if this can be achieved within the present scheme of distinction between "formal" and "informal" communication. We could envisage a trend towards more and more formalizing "informal" communication with the additional corollary that it adds to the protection of the intellectual property of the individual researcher within a research institution. This is worth to be considered within scientific communication.

In the next section we will attempt to take a strategic approach to the concept of scientific communication by a rational and critical analysis of the scientific communication market and its four main functions that we have already discussed anecdotally.

In taking this approach we acknowledge that we are in need of a clear methodology to analyse a structural change that is of crucial importance to scientific publishing as the notion of "must have" information might well be shifting.
Furthermore, we assume that a future system will not be incommensurable with the present, but rather have a high degree of correspondence. This assumption then justifies the choice of defining a set of communication functions that are each by definition invariant to environmental changes. However, environmental changes may well have an impact on the balance of these functions.

In summary, by describing and analyzing a functional change of scientific communication it is implied that this change will be rational and commensurable. This also implies that the developments are considered to provide important opportunities for the presently existing "information industry".

4. Analysis of scientific communication

4.1 The market.

In the most general sense we can state that scientific communication takes place between researchers, mostly acting in some sort of capacity as authors and readers. Their objective is to exchange (units of) information. The market place of scientific communication consists of authors and readers as generic actors or stakeholders. Authors are not only stakeholders of this marketplace by authoring a unit of information, e.g. such as a scientific article or by providing a set of data, but they are also heavy users of this market place as they want their product being made available for all readers. Furthermore, their product is their main expression of accountability within the research enterprise. They claim in this way their priority of discovery. This is a long-standing practice. Already "since the end of the seventeenth century this priority of discovery is the norm and prior journal publication its criterion" (4b, 19).

We can state (4a, 21, 22) that authors want to publish **more** and have their product widely available while readers want to read **less**, but want to be informed of all that is relevant for their research at hand, they want this information available just in time, and they want to be guaranteed that they can and will be informed of all that is relevant to them.

From these arguments we deduce that a unit of information, be it a journal article, dataset or otherwise, is not a functional unit of communication, but requires the interaction with either the author or the reader or both to become a functional unit or a set of functional units. Thus scientific communication is defined as the ensemble of functional units, whereas scientific information is the ensemble of units of information.
Within this definition it is inconsistent to assume that a unit of information can separate an author's market from a reader's market. It rather shows that such a separation cannot exist. This means that we reject a linear view of the market, and this is consistent with the well-known fact that the scientific communication market is a market with a strong, direct feedback system.

Thus the scientific communication market, or short the market, consists of authors and readers (actor pair) as generic stakeholders. They require (sections 2 and 3) availability and retrievability (accessibility pair) of all sorts of units of information with the objective to generate questions and to provide answers (content pair) in order to apply them in science or technology (applicability pair). (We will use the word science when the application is part of the scientific feedback loop and technology when the application is brought outside this loop into another regime).

Each pair is seen to have a more deterministic and a more indeterministic component resulting in dynamic, sometimes opposing interactions. These four "complementary" pairs represent the main forces in the market and are visualized in Figure 1. (Most generally, the forces can be grouped in a tetraeder with in each vertex a force. There are four triangular planes with each three forces in its vertices. By observing that only those planes are relevant that contain both the actor and content forces, this tetraeder then collapses into Figure 1).

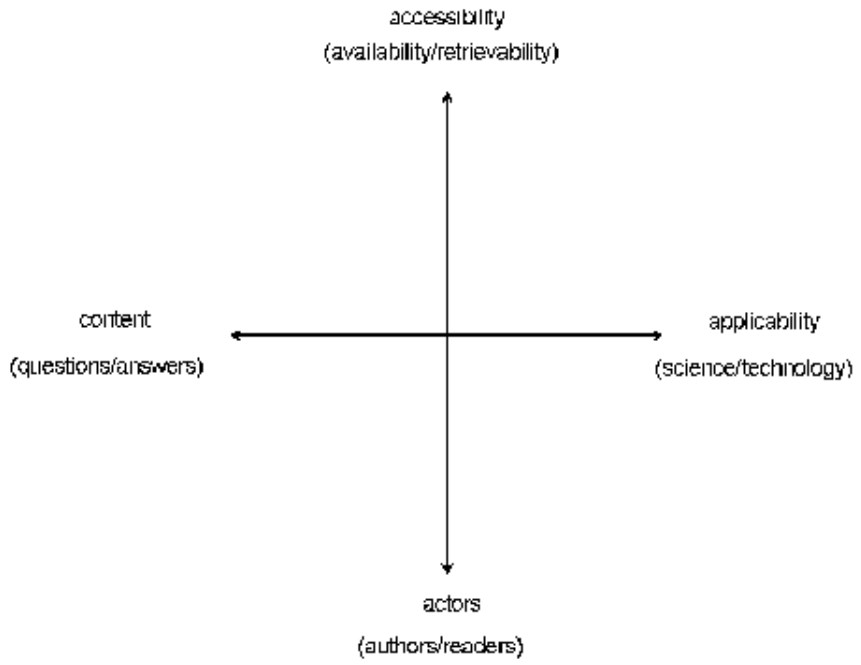

Figure 1:The four forces in the scientific communication market

The vertical axis is seen to describe more the market dynamics and modes of transaction whereas the horizontal axis describes different aspects of the content being negotiated in this market. The market is defined as the place of balance of these forces, as an "agora" of scientific conduct and discourse.

If we accept this description of the market, an immediate conclusion is that there is no such thing as an information market, but instead there is an ensemble of units of information creating an "information space". In this view, libraries and publishers belong to the information or product space that is a subset of the generic scientific communication market. From this description it becomes obvious that the present developments in information technology, and especially the Internet, do represent an important empowerment of the market's main stakeholders, the author and the reader.

4.2 Functions in scientific communication

As stated in the previous section we have argued for a functional analysis of the market. This approach is consistent with our environmental analysis of the developments of strategic research. In analogy with our analysis of the market we will try to identify the main functions of scientific communication.

Following (23, 4, 22) we define as the familiar main functions of scientific communication: the registration, awareness, certification and archive functions. In a similar way as with the market, we can visualize these four main functions as in Figure 2. (Like before with the four forces, we can group these four functions in a tetraeder. And again by observing that interaction planes are void when they do not contain the registration and the archive function, this tetraeder then collapses into Figure 2).

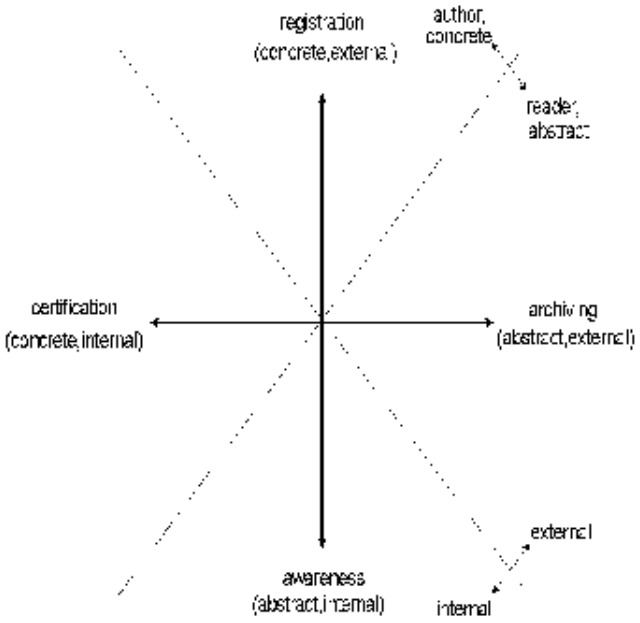

Figure 2:The four functions of scientific communication

Like in the discussion of the market we arrive at two axes: the vertical axis describes registration and awareness which can both be seen as different aspects of scientific observation, whereas the horizontal axis describes certification and archiving which can be seen as different aspects of scientific judgment.

This interpretation shows some similarities with the familiar description of the young Jung (24) of the four main functions of psychology which he grouped into two pairs of opposing functions: the observation functions of experience and intuition, and the judgment functions of feeling and thinking. In our case we find the observation functions of registration and awareness, and the judgment functions of certification and archive. Awareness has thus some more intuitive observational aspects and archiving is assumed to require filtering, or judgment.
We mention this analogy as it will prove useful for a further detailed description of classifications of the communication functions which allow to draw further conclusions on the development of these functions, and the market place.

Inspired by this early work of Jung (24) we arrive at a universal, functional classification: the registration function is both a concrete and objective function, the awareness function is abstract and subjective, the certification function is concrete and subjective, and finally the archive function is an abstract and objective function. There is a half plane of two objective functions, and a half plane of two subjective functions. Similarly, there is a concrete half plane and an abstract half plane. Following the familiar classification of the communication functions into author and reader functions (23) we see that the author functions are concrete and the reader functions are abstract.

This classification is of relevance as a concrete, objective function is by definition an explicit and external function (registration), an abstract and objective function is implicit and external (archive), a concrete and subjective function is explicit and internal (certification), and an abstract and subjective function is implicit and internal (awareness).

Inspecting Figure 2 we see that the subjective communication functions are the functions that are internal to the research process itself, whereas the objective functions are external to the research process. By their nature registration and archiving can easily be outsourced within the market to the product space, viz. the publisher and the library. Whereas in this description we tend to focus on the functions, and for obvious reasons as it leads to important insight on what activities can be outsourced by the research community, we should realize that scientific communication results above all from the interactions or rather transactions between the functions.

The transactions include the transfer of content (primarily the author-reader interface) and the transfer of (consolidated) knowledge (primarily the subjective-objective interface). The latter is in particular important for strategic research as it determines largely its degree of applicability.

Figure 2 shows in a succinct way the overall communication process as it is embedded within the research process, and which parts of this process can be externalised out of the research process.

As an illustration of the four communication functions, let us briefly analyse the birth of the first research journals, Le Journal des Sçavans (Paris) and the Philosophical Transactions by the Royal Society of London. One may assume that the main reason for the birth of these journals was the growth of scientific activity in the seventeenth century and the concomitant break down of the author driven communication system of that time of writing letters reporting their recent research results to author selected readers, and of writing compilations of their work in the form of a book. As a result relevant readers were not evenly informed and the scientific enterprise got out of phase resulting in a loss of effectiveness and efficiency. Thus the birth of the journal was primarily awareness driven. It should be noted that this was assisted by the important technological developments that allowed the deployment of an efficient postal system in Western Europe at that time. Thus one might see the birth of the journal also as technology driven, however technology seems more a necessary facilitator than a boundary condition. By organizing the editorial office by appointing Mr Henry Oldenburg as the journal's editor and by having the submitted articles reviewed by members of the Council of the Society, it was the Royal Society that took charge of the registration and certification functions, whereas the journal developed itself quickly as the archive per se.

Some of these aspects are nicely demonstrated by citations from a correspondence between Oldenburg and Robert Boyle presented in Table 1 , which are taken from Merton (16). Indeed the citations illustrate the importance of registration for reasons of priority and emphasize the point that **the** archive must be lasting and useful.

Table 1 : *Citations from correspondence of Henri Oldenburg - Robert Boyle*

O 1. The Society alwayes intended, and, I think, hath practised hitherto, what you recommend concerning ye registring of ye time, when any Observation or Expt is first mentioned.....

O 2. have declared it again, yt it should be punctually observed: in regard of wch Monsr. de Zulichem (Huygens) hath been written to, *to communicate freely to ye Society*, what new discoveries he maketh, or wt new Expts he tryeth, the Society being very carefull of registring as

well the person and time of any new matter, imparted to ym, as the matter itselfe; *whereby the honor of ye invention will be inviolably preserved to all posterity....*

O 3.This justice and generosity of our Society is exceedingly commendable, and doth rejoyce me, as often as I think on't, chiefly upon this account, yt I thence persuade myselfe, yt all Ingenious men will be thereby incouraged to impart their knowledge and discoveryes, as farre as they may, not doubting of ye Observance of ye Old Law, of *Suum cuique tribuere*.

B 1: I mightly justly be thought too little sensible of my own Interest, if I should altogether decline so civil an Invitation, and neglect the opportunity of having some of my Memoirs preserv'd, by being incorporated into a Collection, that is like to be as *lasting* as *useful*.

In conclusion, the four functions provide a consistent analysis of scientific communication, both formal and informal. It may be questioned if these four functions together with the transactions between them provide a comprehensive description of scientific communication which is a condition for the strategic approach that we have taken, in particular if we want to apply the functions to arrive at conclusions on strategic repositionings in the market which are based on strategic correspondence (see next section 5).
As such, this approach may be seen as an empirical approach to a conceptual discussion.

External functions: registration and archiving

Within an electronic communication environment the present focus of development is on the two external functions. The function of registration is already fully matured with the exception of the intellectual property aspects of integrity of the communication and copyright issues. For the archive function we have observed that both publishers and libraries are creating electronic archives or warehouses of information material under their control allowing distribution of this information through a variety of different media. First attempts are being made to connect these archives into a more distributed system that forces to introduce conditions for transparency. This raises a number of key issues on the responsibility for such a distributed system or the organization of such a distributed archive. Do we need to standardize technology and to what extent? Will such an archive allow the author and reader to integrate the information into a personal archive? This is no doubt desired and should be one of the main objectives of such an archive. From Figure 2 we see that the archive function serves as a main transaction function or sluice between author and reader. This raises the immediate issue of integrating informal communication into the platform of such an archive leading to an integration of formal and informal communication, which means formalizing informal communication into one and the same platform and management system. A result of these developments will be that the now distinct roles of publishers and libraries will be merged to become nodes in the overall management of scientific communication.

Internal functions: certification and awareness

The certification function has been and is under continuous discussion and a wide variety of schemes are being proposed. It is particularly the certification function that might develop most under the strategic research regime, i.e. it has to be investigated how "economic" aspects related to the concept of "centers of excellence" will influence certification of research results. Gross (19) already describes peer review as a negotiation on the level of claims permissible in a scientific article. The higher the level, the higher the article's status; the higher the status, the more difficult the negotiations. And indeed, under conditions of strategic research the negotiations might well become even more difficult and the role of the referee needs further attention (12, 16). Merton (16)

stresses in particular the strong relationship between intellectual property, and thus applicability, and the referee system. The referee system provides a clear authoritative system for the research enterprise and its rules of conduct will continue to be discussed within the wide context of the goals and applicability of research (see also 25). It makes a difference if a referee, when in doubt, is inclined to accept or reject an article. Intermediate schemes are also being proposed (26). Referees can add comments to an article that allows the author to make revisions or, if so desired, to withdraw from publication.
The transformation into a real communication network should address the issue of certification, and indeed the question arises if certification can and will remain primarily restricted to research internal methodological arguments (internal heuristics) or that more and more external elements of a more economic nature will be added (external heuristics). In this context economic means that it may be more rational, and thus sufficient, not to use the best in the methodological sense. This development could change the rules for the advancement of science, or has already changed these rules by creating "centers of excellence". As we have seen, we may be in need for a new normative structure specific for strategic research.

No doubt this will be reflected in the way science will be communicated. To illustrate this point: over the last decades we have witnessed a clear change in emphasis from the collection of information proper, such as data, towards the application of data which requires new schemes of clustering.
In terms of Popper (27) we are less concerned to answer the questions of the empiricist such as "how do you know" and "what is the source of this assertion" but focus instead on "what is the purpose" of strategic research and "what does it answer". This represents a clear shift towards more mature scientific communication at large.
The most difficult function, the awareness function that is of course the real engine in the communication process is also being tackled. Research on the modularity of scientific communication has been started (4).

Research on science indicators is key to this function (28). Science indicators also play an important role in the discussion on certification.

The discussion on intellectual property and its consequences for certification and registration signalises that a discussion on the normative culture in (strategic) research is needed.

Discussion and concluding remarks

An alternative to the used functional analysis is to analyse the needs of the stakeholders in the market place, and this is reported in the literature (4a). Within our present methodology, the analysis of needs must be seen as a more tactical (or mechanical) approach to scientific communication. Such an analysis can then be generalized into a description of functions (21, 22) in order to bring the discussion to the strategic level. Within this context of developments of scientific communication three needs (4a) are relevant. This is the need for more general scientific standards that determine the social structures within the scientific enterprise, the need for a universal platform for communication as well as ownership protection for all stakeholders in the market. We have seen in the discussion above that the issue of intellectual property both for the individual researcher and the research institution will probably become even more important than at present.
If we look at the (normative) structure of science according to Merton (16) the claims of universalism and communalism are the most relevant to this discussion. From communalism it is often derived that knowledge is a common property and communication is a public process. At the same time, we have seen that communication is a complex, value-added process and that the applicability and management of knowledge is of main concern. From the discussion of the

functions it may be clear that the functional description contains the above mentioned needs and sets them in a wider perspective. The product space can then be defined at the operational level and indeed the product space is embedded in the external functions of scientific communication. It may be noted that the set of functions does give a complete description of the configuration of scientific communication.

It is interesting to see that in reducing the forces and functions tetraeders to the representation of Figures 1 and 2 (section 4.1) we used different criteria for the market forces than for the functions. With respect to the market forces we postulated that the actor and content forces are indispensable, as these forces are most generic and internal to the market as opposed to the external forces of accessibility and applicability. With respect to the functions we postulated that the external functions are indispensable.

These choices are consistent if we consider the dynamics and time aspects of the market and its functions. Although we have seen that the overall market process and the overall communication process cannot be linearized in time as these are feedback processes, one can linearize each individual process like one can linearize each individual research process (see e.g. 15). Taking the individual processes it is easily seen that the individual market process is initiated by its internal forces whereas the individual communication process is initiated by its external functions. The overall market process can be seen as a superposition of individual processes, but not as a simple linear superposition, just as the communication for different phases of the research process cannot be described as a linear superposition of specific communication functions. An interesting consequence of this argument is that registration must precede certification, which indeed it does. In turn, certification can result in lifting registration. Submission of an article starts certification and can be the final registration if the article is published as is. Revisions arising from certification may lead to registration (as accepted after revisions). Rejection leads to lifting the existing registration.

4.3 Some consequences

The above description of the market and its functions has aimed to provide a consistent description of the main forces in the market required to generate knowledge in the widest (societal) sense, and how scientific communication provides dynamics to this market. Scientific information has been seen to be a part of this market, but at the same time cannot be seen as an independent market. It is a subset of scientific communication as a whole.

All four market forces are decisive for the rate of "research capital" return. Such rates of "research capital" return cannot be defined for any possible, incomplete subset of the entire market. As a consequence, one cannot separate modes of applicability from modes of accessibility, analyse information independently from the other forces, or even separate the actor pair into an author’s market and reader’s market.

Figures 1 and 2 show clearly the crucial role of intellectual capital, and indeed it is fair to see intellectual capital as a most important engine of societal development. At the same time it is shown that there is a point of friction between intellectual property at the individual’s level and at the institutional level, or even at the level of a (national) network or of an entire community, which again has important consequences for the certification function. This raises some very interesting questions on the complex issue of ownership within the market.

It seems safe to conclude that the forces and functions together provide a useful description of the dynamics of the market as a whole, or the value created in the market. As such it replaces the familiar linear value chain which in itself does not do justice to the inherent multidimensional

nature of the feedback system within the market.

5. Future developments

5.1 Strategic repositioning?

In the previous section we have developed a strategic model of the market based on four forces of complementary pairs: the actor (author/reader), accessibility (availability/retrievability), content (questions/answers), and applicability (science/technology) force. This strategy emphasizes a market driven, and not a technology driven, development, and in particular the empowerment of the market's generic stakeholders: the actor force.
Furthermore we described the relations between the main functions in scientific communication. For an analysis of a future development in the market two questions come to the fore:

- how will these functions develop?
- do we need in the market a new division of functional tasks or a new functional division?

The first question has been discussed in the previous section.

In this section we will focus on the latter question which is a question to a future structure and organization of the market. As we have noted before, in the present market the principal stakeholders have outsourced a number of functional tasks to other stakeholders such as publishers, libraries, agents, etc. or "insourced" to institutions such as societies, universities or research institutions. This accounts in particular for the external functions of registration (publisher, society) and archive (publisher, library) and the logistics aspects of the internal certification function (publisher, society).

We will assume that changes will be rational as opposed to paradigmatic. This means a change at the conceptual level of functional development (or added value) rather than an empirical development. We reject a paradigmatic change, as it would imply that such a new structure would be incommensurable whereas we adhere to strategic correspondence for reasons outlined above in section 3. This means that the present system should evolve in a rational way with the developments in the market.

Key to future developments is the recognition to be received by the individual, the research institution and the funder be it a national or a transnational funder. Following Merton (16) we realize that a concern with recognition is symmetrical to a concern with advancing knowledge. Where we have noted that strategic research implies a new entrepreneurial regime for the research institutions it seems safe to assume that the recognition depends on the applicability of research results. This demand for applicability will add an external component to recognition. No doubt, this will affect the balance of forces in the market as it potentially leads to other choices in answers and questions, and sets other conditions for the use, and availability and retrievability as a whole. These developments will determine how we will perceive the certification function that then automatically translates into changes of the registration and archive functions, and thus will affect the degree of outsourcing.

These developments may well lead to conflict, and indeed some literature (5) mentions an "information crisis". The present analysis based on strategic correspondence may provide solutions to this perceived crisis.

5.2 Methodology

The present structure and organization of the market have been seen to have a high degree of outsourcing of the external functions to other stakeholders in the "knowledge industry". These functions are mainly performed at the operational level and add restricted intellectual value, i.e. in the selection and processing of information.

In other words, the knowledge industry is a complex network of different stakeholders such as authors and readers, organized in different kinds of research institutions, libraries, societies, publishers, intermediaries such as subscription agents, and not least the enabling industry and software houses. In this context we also see a development that the institution's departments of computer technology create alliances or even merge with the institution's libraries. This network is characterized by a high degree of subsidiarity: the stakeholders enjoy a high degree of mutual strategic interdependence. The outsourcing concerns the transfer of content in the market and the management of this content, i.e. it is focused on accessibility in the market. The issue then is if this task of facilitation management should not be reintegrated into the market as in an electronic environment we cannot conceptually separate accessibility from applicability and content. The trend in the market does not allow a simple operational separation either, as we have seen.
This would be consistent with the development of strategic research with its dynamics emphasizing problem finding and applicability over curiosity (section 2). Its focus on transdisciplinary research requires not only transfer of explicit knowledge, but also implicit knowledge. This lends a strong argument for reintegration, as it adds a new dimension to applicability of research and thus integrity in communication. No doubt such reintegrated or comprehensive scientific communication services must be highly dynamic and commercial, not least for the "strategic research enterprise", as these will seek optimal return on research capital investment. Again, intellectual capital is key to this development.

5.3 Organizational Consequences

We may state that knowledge is a virtual product, as being immaterial in itself, but looking real, and certainly having some very real consequences (29).
Scientific communication nowadays means electronic communication or electronic dissemination of "knowledge". This implies a virtual carrier for the virtual product, making use of a virtual memory. Therefore, the question seems legitimate if a virtual organization should not be the appropriate, new organization for the market (30, 31).

We follow the usual definition of a virtual organization (29) of being a special case of an organizational network which is an identifiable whole vis a vis external stakeholders. An important characteristic of a virtual organization is its distributed ownership that distinguishes it from a co-operative conglomerate. A virtual organization is mainly representing a balance of forces in the market.
At first inspection of Figure 1 and 2 it seems that the market as a whole qualifies as a virtual organization. The market also shows clear aspects of distributed ownership. However, this conclusion is not correct if we define the market in the present sense, as the 'information industry" i.e. limited to the presently outsourced accessibility section of the entire market. The "information industry" is a separate outsourced operational subset of the entire market. Adherence to this organization may well lead to inflexibility in the development of the entire market.

Looking back at the historical development of the scientific journal as the vehicle for scientific communication, we can see that the Royal Society of London, and other societies for that matter,

represents in this matter a virtual organization, in particular as the research enterprises of that time were almost tautological with individual researchers, or small groups of researchers. Indeed, all forces in the market and all functions are integrated in the concept of the society with its members and institutions.

If we include in the market not only the transfer of information after the research process, but the exchange of all kinds of information during the research process as well, e.g. in round-robin experiments, and this is consistent with the used definition of scientific communication, we can firmly conclude that the scientific communication market, including all its partners, qualifies as a virtual organization.

The essential difference is that if we also include information exchange during the research process, we consider communication within the entire research process: research and communication are viewed as parts of one organization. If we limit ourselves to information exchange after the research process only, and again this would be inconsistent, we can see communication and research as two distinct organizations. In the latter case, communication is purely restricted to the functions; in the former case, we also consider the transactions between the functions.
This implies reintegration of those functions and thus tasks that are presently outsourced to "external stakeholders".
Reintegration responds to the stronger needs for new ways of return of research capital investment that are implicit within strategic research.

The question then arises if a new division and separation of functions is feasible. It seems obvious from the present discussion that scientific communication as a whole cannot be organized independently from the research market if we take into account the boundary conditions of (strategic) research.
What can, and thus probably will, be organized independently is the communication network, i.e. the technological network, including information of a variety of nature and forms. This will no doubt be a distributed network and its core will be a distributed archive as discussed in section 4. The main tasks that presently can be foreseen for such a network are content (question/answer), storage and management of communication (availability/retrievability) and structure of communication (a condition for applicability). E.g. a modular structure for scientific articles has been proposed to replace the present linear structure (4b). Such a structure is supposed to strongly enhance the accessibility and thus applicability of elements of information and to allow a seamless and smooth integration with modules of other articles or other information sets and collections.

These developments will require a reorganization of the knowledge industry and a new division of tasks and responsibilities between the stakeholders. In such a unified, distributed system strategic management needs to be clearly separated from operational management. To aim for such a new separation is an important issue for all stakeholders concerned.
It will call for new alliances or consortia between stakeholders that presently form separated subsets or groups within the market.
For a real virtual organization this would further imply cooperation within a somewhat nomadic context, without a strict hierarchy and not allowing "sedentary" relations (29) as boundary conditions for such alliances. No doubt, these conditions carry important consequences for the present stakeholders in the "knowledge industry" and in particular for the stakeholders of the more restricted "information industry".
The above implies a new assessment of the distribution of ownership in such an organization as content and applicability are major forces of this distributed communication network. Content ownership can then not be seen as restricted to ownership of content transfer after the research process, and unrelated to its applications.

5.4 What is scientific communication?

In the above we have discussed scientific communication in its relation to the (strategic) research process and to scientific knowledge. As a consequence we cannot ask the question: what is scientific communication? in isolation, but it means asking the question: what is science and what is scientific knowledge?

In this article we have discussed the relation between strategic research and scientific communication, and the trends in these processes. In doing so, we have taken the view that science policy or research policy becomes more and more an innovation planning policy resulting in strategic research. In strategic research problem finding has been seen to play an even more important role than it did before (13).

Scientific communication then serves to facilitate strategic research.
Taking the approach of strategic correspondence we have touched on a number of methodological aspects of scientific communication and formulated some new aspects of the market and its functions, and how to organize this market.

The discussion has left quite a number of aspects untouched and resulted in many questions that need to be answered further. These questions are relevant to be further addressed within the framework of a (strategic) research programme on scientific communication as viewed within the context of developments in research and education.

Nevertheless, it seems safe to conclude that the general direction that research policies, and thus, research, have taken make the process of reintegration and reorganization of the scientific communication market a necessity. This may then in turn lead to new schemes of dividing this market into more or less separated entities. Or in other words, strategic repositioning within the scientific communication market seems inevitable!

6. Summary and conclusions

This article provides an analysis of the transformation of the scientific information chain into a scientific communication network. An attempt has been made to develop a methodology to investigate this transformation. The resulting methodology enables us to arrive at a set of observations, conditions and results for this transformation.

We analyse the phenomenon of strategic research (section 2) which adds a clear "economy of scope" to scientific research. Science policies all over the world result in transforming research institutions to so called "centers of excellence" which then must become transnational, entrepreneurial institutions. The emergence of these institutions leads to further consequences for their funding. It is readily acknowledged that most research has over decades or even centuries been international research, but this research was always performed under national or for that matter supranational funding regimes. Strategic research has been seen to be society driven in a fundamentally different way and we have analyzed some of the economic drivers that are relevant in this development.

For our discussion of scientific communication intellectual capital and thus internal research time seems the most crucial parameter of scarcity. Return of strategic research capital investment is the overriding issue for such emerging research institutions, and this means to retain control over their intellectual property. As corollary it becomes evident that a distinction between industrial research

and academic research becomes even more blurred. Within this context of strategic research we touched on a number of familiar questions (11):

- what does research production consist of
- who are the actors and what is their competence
- how can we define the underlying dynamics
- how is agreement being obtained between the actors
- what forms of organizations are assumed, and
- how can we describe the overall dynamics?

In this article we restricted ourselves to the communication aspects of the underlying developments. We have established that strategic research calls for new forms of knowledge management for the individual researcher as well as the research institution (section 3). Within this context we have formulated some questions on the future role of publications within research and the type of publications needed. We have seen a shift in focus from e.g. data collection to data validation and clustering as an example that the present rate of production of research needs alternative ways of certification of research information, as otherwise strategic research may fall the victim of the so called information crisis. Such a crisis may well retard the research progress as a whole. One of the conditions for scientific communication is that it should provide effective and efficient ways of filtering new research results that allow proper "aging" of research models and theories. Thus certification should be subject to the conditions of strategic research for obvious reasons of consistency.

The information technology developments have been seen to lead to further empowerment of the key stakeholders in scientific communication: the author and the reader. As such, one could argue that there is a genuine technology push.

For our analysis of the transformation of the linear information chain into an interactive scientific communication network we have adopted a methodology of development of a strategic analysis rather than an empirical or operational analysis (section 4). An obvious condition is selfconsistency and this could be achieved by describing the scientific communication market by four forces of complementary pairs: the actor, the accessibility, the content, and the applicability pair.

The forces allow an overall description of the dynamics of the market: this description provides a frame for the various aspects of time, space and action (23) that are relevant within this context.
It further reflects the unified nature of this market that is essentially a multidimensional, highly complex feedback market system. And indeed, there is this scientist’s desire of one unified collection of research achievements which then is distributed over many subcompartments, and results in a number of organizational conditions.
Within this new "value network" of forces we have defined a set of four functions for scientific communication. These functions are the registration, archive, awareness and certification function. The developments of these functions in an electronic dissemination regime have been discussed. It was seen that the present focus of development is on the registration and the archive function, where in particular the development of the archive function raises key organizational issues. It is expected that within the context of strategic research the certification function may require fundamental rethinking.

The observed development of the value chain for scientific information to the scientific communication value network of a distributed system has lead us to ask the question of a future organization of this market (section 5). We have seen that within this context a number of aspects that are ascribed to the "virtual organization" are of relevance within this context.

In particular, with so many stakeholders involved, and given their widely different roles within the system and the conditions imposed by knowledge management within strategic research, the ownership issue becomes a complex one. The virtual organization seems promising in providing some answers and rules for a configuration of distributed ownership. We have noted the desire for a unified collection and it seems clear that this is only achievable under conditions of distributed ownership and complementarity between all stakeholders involved.
These changes could possibly lead to a conflict or a crisis within the present information industry. The methodology of strategic correspondence gives some solutions if the stakeholders express a clear interest in adhering to the new conditions imposed by the forces in the market.

Key is to come up with a solution for the strategic management of the distributed scientific communication market. This means finding the right balance and interface between private and public interests and consistent with the main aim of serving strategic research with its particular emphasis on applicability, intellectual capital and, as a consequence, integrity of its communication. This requires a broad, international programme inviting the majority of stakeholders, private and public, in defining, implementing and executing a co-ordinated set of projects each focused to test different issues and aspects of the strategic repositioning of the scientific communication market.

No doubt much more research has to be done. It is readily acknowledged that many explorations and observations in this article can only be considered as first, initial attempts to develop a more mature methodology for a research programme on scientific communication. Such a programme should be seen within the context of strategic research and should develop and be based on clear heuristics.
We make a strong plea to develop such a research programme as an independent research discipline. This research is needed as so much is seen to be still relatively unexplored whereas our research progress, and thus societal progress, depends so much on our ability to manage, and thus communicate, our scientific knowledge, and not only scientific knowledge, in an effective and efficient way.

Research issues that come immediately to the fore are issues related to the market transformation that we are witnessing at present with the aim to develop a clearer picture of forces in such a future market and the applicability of the virtual organization to further develop each of the communication functions with some emphasis on the certification and awareness functions as these are decisive for the applicability of our research efforts. This research will involve technological communication developments such as replicable knowledge modules, search agents representing research profiles, editorial research and scientometric/bibliometric research (32) just to name a few aspects. With respect to the latter, it seems clear that electronic storage and dissemination will add new dimensions and will allow new dynamics to scientometric/bibliometric research. With respect to the archive function conditions for transparency need to be further explored.

The research programme should allow for empirical testing of its results, which seems feasible within an electronic environment allowing dynamic simulations.
Key in such a research programme will be to analyse and develop new structures and types of publications. A modular structure has been mentioned and is now being investigated, but also the anagram of progress as developed by Christian Huygens in the seventeenth century (19, 20) may inspire to come to new structures and types, especially when the distinction between formal and informal communication might be lifted.
If, and how, this will happen is a question that is most relevant to the functioning of the entire system. Connectivity of communication and its auxiliary tools such as identifiers, indexing and classification need to be considered as well.
In short, we need a research programme of (meta)communication incorporating relevant elements

of (meta)science.

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Footnote

In life, there are no solutions. There are forces in motion: they need to be created and solutions follow.

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