Chapter 2
The Communication Turn in Philosophy of Science

Whereas knowledge has often been attributed to individuals or, from a sociological perspective, to communities, a communications perspective on the sciences enables us to proceed to the measurement of the discursive knowledge contents. Knowledge claims are organized into texts which are entrained in evolving structures. The aggregated citation relations among journals, for example, can be used to visualize disciplinary structures. The structures are reproduced as "ecosystems" which differ among them in terms of using specific codes in the communications (e.g., jargons). Unlike biological DNA, these codes are not hard-wired; they can be changed in the communication. The sciences develop historically along trajectories embedded in regimes of expectations. Regimes exert selection pressure on the historical manifestations. The evolutionary dynamics at the regime level induce crises, bifurcations, etc., as historical events.

In addition to his many discoveries, Galileo changed the philosophy of science of his time by considering the Book of Nature no longer as God's Revelation, but as a text open to debate and revision. In his well-known Preface to the second edition of the *Critique of Pure Reason* (1787), Kant reflected on this crucial step in the development of the modern sciences, as follows:

> When Galileo caused balls, the weights of which he had himself previously determined, to roll down an inclined plane; when Torricelli made the air carry a weight which he had calculated beforehand to be equal to that of a definite column of water; or in more recent times, when Stahl changed metal into lime, and lime back into metal, by withdrawing something and then restoring it, a light broke upon all students of nature.[…] Reason, holding in one hand its principles, according to which alone concordant appearances can be admitted as equivalent to laws, and in the other hand the experiment which it has devised in conformity with these principles, must approach nature in order to be taught by it.[…] It is thus that the study of nature has entered on the secure path of a science, after having for so many centuries been nothing but a process of merely random groping.

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Beyond Kant, who focused on the transcendental relation between individual reasoning and truth, Galileo was thoroughly aware of the communicative nature of the new sciences. For example, he entitled his books *Dialogo* (1632) and *Discorsi* (1638), respectively. The scholastic form of a *disputatio* had been used by him in earlier work (e.g., *Disputatio de coelo*, 1616) and was still in use by his adversaries.[1] However, this monological style was increasingly abandoned in favor of dialogue as the new mode for generating, validating, and reproducing knowledge (Biagioli, 2003). Discursive knowledge is shaped in communications among reflexive participants with reference to supra-individual horizons of meaning.

The cycling of discursive knowledge in communication networks makes the criteria stable and then potentially global. In his book *The Structure of Scientific Revolutions*, Kuhn (1962) used the "Copernican turn" of the sixteenth and early seventeenth century—Galileo's heliocentric worldview—as the prime example of a paradigm change. The Scientific Revolution changed the communication and control structures in the sciences at the above-individual level.

2.1 Discursive Knowledge

A communication-theoretical perspective on the philosophy of science can be elaborated into empirical research: the dynamics of theory development can be operationalized in terms of communication dynamics (Krohn et al., 1990; Rorty et al., 1992). The modern sciences are discursive and mediated. The mediation of knowledge production by scientific literature was historically made possible after the invention of the printing press in the second half of the fifteenth century (Eisenstein, 1979, 1983; Luhmann, 1981). Free presses for printing Protestant translations of the Bible were organized first in Geneva and Lausanne during the sixteenth century, and then in Amsterdam and Leiden in the early seventeenth century. During most of the seventeenth century, however, scholars still communicated by means of letters.

In 1665, the *Philosophical Transactions of the Royal Society* appeared as the first scholarly journal, followed in 1666 by the *Journal des Sçavants* in French. The increased circulation of knowledge triggered a bi-furcation between the knowledge production flow and the control mechanisms during the Scientific Revolution. The further organization of the sciences as written knowledge in scholarly journals followed as an achievement of mainly the eighteenth century (e.g., Bazerman, 1988). The modern citation was gradually invented in the course of the nineteenth century (Price, 1961, p. 166). A cultural evolution of communications in layers has thus been induced.

The main function of a reference was first, for example, mentioning those who had attended an experiment. The argumentative function in relating texts to other texts gradually emerged in scientific communications, leading first to the institutionalization of the sciences; for example, at German universities in terms of Chairs during

[1] E.g., Orazio Crassi, (1619). *De tribus cometis anni MDCXVIII disputatio astronomica*, Rome.

the 19th century (Stichweh, 1984). The institutionalization can be considered as a retention mechanism of novelty (cf. Freeman & Perez, 1998), but the new forms of organization changed also the nature of the communications. The modern reference, for example, was invented as a global standard only as recently as the turn of the twentieth century (Leydesdorff & Wouters, 1999).

The referencing networks *select* upon the referenced ones, thus allowing for communications with greater specificity. In our time, hyperlinks relate documents on the internet in terms of a hypertext; references are embedded in texts as subtexts, etc. Subtexts and hypertexts can be considered as different contexts of the textually embedded knowledge. The relationships between these layers of texts, sub-texts, and super-texts have been transformed by the emergence of electronic communication and the internet. More specifically, the real-time availability of virtual hypertexts is changing the systems of referencing, indexing, and retrieval by adding degrees of freedom to the evolving communications.

From an evolutionary perspective on scientific communication, the texts provide variation (Callon et al. 1986; Law & Lodge, 1984; Hesse, 1980). By referencing, a subset of these texts is selected. References and citations can thus be used as indicators of selection processes. Words and co-words are relatively volatile indicators, while citations may function as symbols and refer preferentially to texts that have been codified. Indeed, citations can be more than ten times as precise as words (Braam et al., 1991; Leydesdorff 1989 and 1997a; cf. Garfield 1955). Baumgartner & Leydesdorff (2014) distinguished between transient and sticky knowledge claims, operationalized as relatively recent citation at a research front *versus* longer-term processes of codification.

2.2 The Modern Citation as an Example of Codification

In the pre-modern era, a manuscript had to be transcribed in a manual process that was prone to error. Nowadays, a new edition of a printed book, however, can be expected to improve on previous editions by updating the content and correcting errors. Knowledge is continuously being revised in scholarly communications (Price, 1965). Thus, one no longer proceeds from an original text (like the Bible) to an inferior copy because of mistakes in the transcriptions. One proceeds from a previous to a next version by rewriting. This process is social, and since the nineteenth century increasingly organized for the objective of technological applications (e.g., in industrial laboratories; cf. Bernal, 1939; Braverman, 1984; Noble, 1977; Van den Belt & Rip, 1987).

The modern citation was invented in the late nineteenth century, but first in the form of references without dates (Bazerman, 1988). This form was replaced with the current format around 1900. Following the invention of the new form, the older form of referencing rapidly disappeared and the number of references began to grow exponentially. For the February issue of the *Journal of the American Chemical Society*

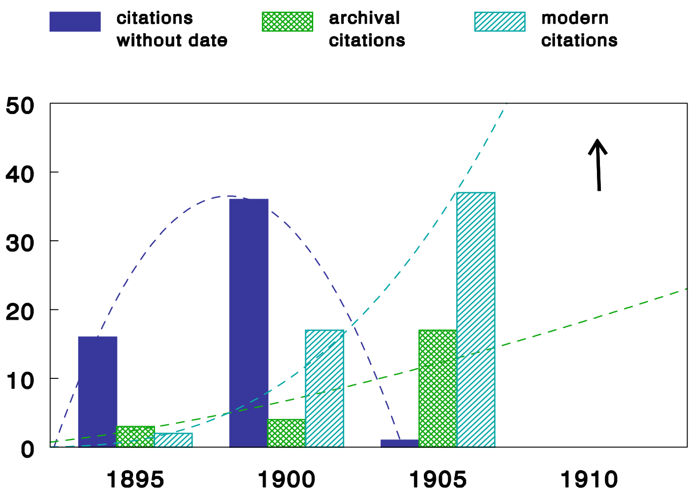

Fig. 2.1 The origins of the modern citation in the Journal of the American Chemical Society (JACS). *Source* Leydesdorff and Wouters (1999)

(JACS) in 1910, the number of modern citations had increased to sometimes more than ten on each single page (Fig. 2.1).[2]

The development of *discursive knowledge* presumes the circulation of meanings as analytically different from the communication of information as texts. The texts are historical instantiations of the development of the knowledge involved. New words are sometimes needed: for example, when "oxygen" was invented in the eighteenth century by Priestly and others to replace "phlogiston"; but at other times the same word is provided with a new meaning (such as "force" in Newtonian *versus* Aristotelian physics). Another theoretical framework can make a difference to both the meaning and the expected information content of the messages that are exchanged (Hesse, 1988; Leydesdorff, 1997; Quine, 1951).

Whereas the communication of information is studied in the information sciences and in scientometrics, the self-organization of meaning in interhuman communications has been central to Luhmann's (1995) efforts to make the theory of *autopoiesis* (Maturana & Varela, 1980) or "self-organization" relevant for sociology. As discussed above (in Chapter One), Luhmann (e.g., 1986) argued that communications carry the self-organization of meaning. However, Luhmann focused on the top layers of codification and its dynamics as domains. An empirically richer understanding of the sciences as processes of communication can be achieved when the underlying processes are also taken into account. Can one distinguish between (*a*) the communication of information and (*b*) the sharing of meanings? How should this difference be modeled and can it perhaps be measured?

[2]The assumption of exponential growth still grossly underestimates the noted observation in 1910, while this curve fits at $r > 0.99$.

2.3 The Communication Perspective

In the philosophy of science, Popper (1935) distinguished between the context of discovery and the context of justification. However, the communication perspective enables us to distinguish three contexts: (*i*) the local interactions and exchanges in *the context of discovery* operating bottom-up and submitting knowledge claims; (*ii*) the validation of knowledge in *globalized contexts of justification;* and (*iii*) the *mediation* between these two levels in terms of texts and discourse. The three contexts are historically interwoven, but they can be distinguished analytically. The context of justification can operate as a self-organizing (and largely anonymous) control mechanism. However, knowledge needs to be instantiated in texts before it can be reconstructed.

Whereas the context of discovery operates bottom-up, control mechanisms in the context of justification operate top-down. Discourses—exchanges of arguments—mediate between these two other levels (Mulkay et al., 1983). Discourses can overflow in exchanges between disciplines (Callon, 1998), as well as mediate between science and society (Gibbons et al., 1994).

The sciences self-organize into disciplines and specialties using specific codes. The codes are not manifest, but operate as selection mechanisms that coordinate the communications. Unlike communities of people, codes in the communication can be stabilized and globalized; communications travel more easily than people (Latour, 1987). Symbolic generalization of the codes at the global level span horizons of meanings. Note that this is an analytical model in which the dynamics are taken apart. Both horizontally (as different codes) and vertically (as different mechanisms), the various subdynamics of communication operate in parallel and can be expected to disturb one another.

Without mentioning—but, in my opinion, building on—Herbert Simon's (1962,1973) theory of complex systems, Luhmann (1975) proposed to distinguish three mechanisms in the dynamics of communication: interactions, organization, and self-organization. From this perspective, the interactions provide variation; for example, knowledge claims. However, this variation has to be organized (e.g., in texts) before its content can further be selected for globalization. Globalization refers to a next systems level in which codes of communication are self-organizing; for example, by disturbing one another.

The construction is bottom-up, but the cybernetic principle is that the selecting next-order level is structural and can take over control as it emerges. This model is also known as reaction–diffusion dynamics (Rashevsky, 1940; Turing, 1952). If diffusion becomes more important than the flux in the production process (for technical reasons divided by 2), the system becomes unstable and can go through a phase transition. A phase transition changes the dynamics of the system irreversibly. Which subdynamic prevails depends on the initial (and potentially random) deviations from homogeneity.

Without having concepts like phase-transitions and bifurcations available at his time, Marx (1867) went to great lengths to explain why the exchange of commodities through the mediation of money ("Ware-Geld-Ware" or WGW) is qualitatively different from the exchange of money via the mediation of commodities ("Geld-Ware-Geld" or GWG; see Marx, ([1867], 1995, pp. 66 ff.).[3] The dynamics of money are more abstract than those of material commodities. The price of a commodity can be considered as an expectation of its value, and thus this symbolic generalization of value in terms of prices enables us to handle greater complexity in the communication and at a higher speed. "Alienation" may follow when the driving forces of social developments are self-organizing and therefore increasingly beyond the control of individuals (Platt & Weinstein, 1971).

Analogously, in the sciences—albeit less frequently than in everyday transactions on the market—the submission of a knowledge claim (usually in the form of a manuscript) relates the context justification to the context of discovery in which new insights have heretofore been shaped. The epistemological status of the knowledge content under discussion is changed by entering into the differently organized layer of communications invoked for validation and justification. However, the context of discovery remains necessary as the source of the historical variation; the context of justification functions as a next-order control mechanism that operates latently alongside the context of discovery. The two dynamics—the historical one of generating specific claims *versus* selections from the perspective of hindsight—can be expected to operate with different frequencies, and also to disturb each other.

By being repeatedly selected, knowledge claims can be stabilized, meta-stabilized, and also globalized as next-order structures and dynamics in networks. However, these constructs remain fragile and in need of reconstruction. Unlike *social* networks, which find their stability in human and institutional agents as carriers of the communications on the ground, communication networks are event-based: communication is an operation that disappears as it happens (Snijders et al., 2010). Consequently, stability is constructed and needs to be explained (Latour, 1987). The reproduction of communication is anchored, on the one hand, in the layer of agents carrying the communications from below; but on the other hand, communications are selected from above at the supra-individual level with reference to next-order structures such as the codes of communication emerging within the communication networks as meta-representations which span horizons of meaning (Distin, 2010). The next-order dynamics is not resting (with a lower frequency) on the underlying ones, but tends to differentiate with a dynamic of its own. This endogenous mechanism can drive a phase transition to a more complex arrangement.

2.4 Operationalization and Measurement

The communication perspective on the sciences as evolving structures enables us to proceed to empirical operationalizations. For example, the variation of scientific communications is visible first in the form of claims in manuscripts (Myers, 1985;

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[3] "Ware-Geld-Ware" can be translated as "Commodity-Money-Commodity;" see Marx, 1995, pp. 66 ff.

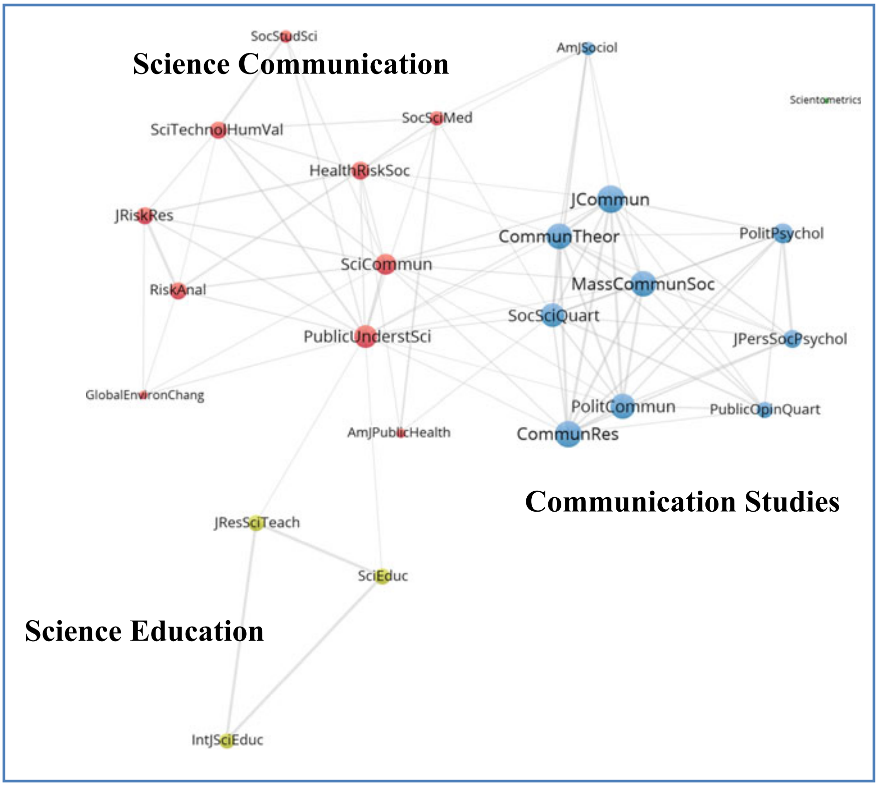

Fig. 2.2 Aggregated journal-journal citation network among 24 journals cited in *Public Understanding of Science* in 2011 to the extent of more than 1% of all references; cosine > 0.1; Blondel et al.'s (2008) modularity used for the clustering in Pajek; $Q = 0.447$.

Pinch, 1985). These knowledge claims are organized into bodies of scholarly knowledge and literature. The literature can be used to visualize the coding into specialisms and disciplines.

Figure 2.2 shows, as an example, the relevant citation environment for the 141 authors who published at least one of the 67 papers in the journal *Public Understandingof Science* (*PUS*) in 2011. After removing the incidental citations (< 1%), three main groups of journals are indicated at this aggregated level: communication studies, science communication, and science education.[4]

Figure 2.2 is based on a matrix of aggregated journal-journal relations among 24 journals cited in *PUS* in 2011. Using papers instead of journals as units of analysis, one can, for example, analyze the references to journals in the 67 papers published in 2011 (Fig. 2.3). While Fig. 2.2. shows how *PUS* as a journal is related to a larger set—providing horizons of relevance—the individual papers published in 2011 reference

[4]Three factors explain 43.06% of the variance.

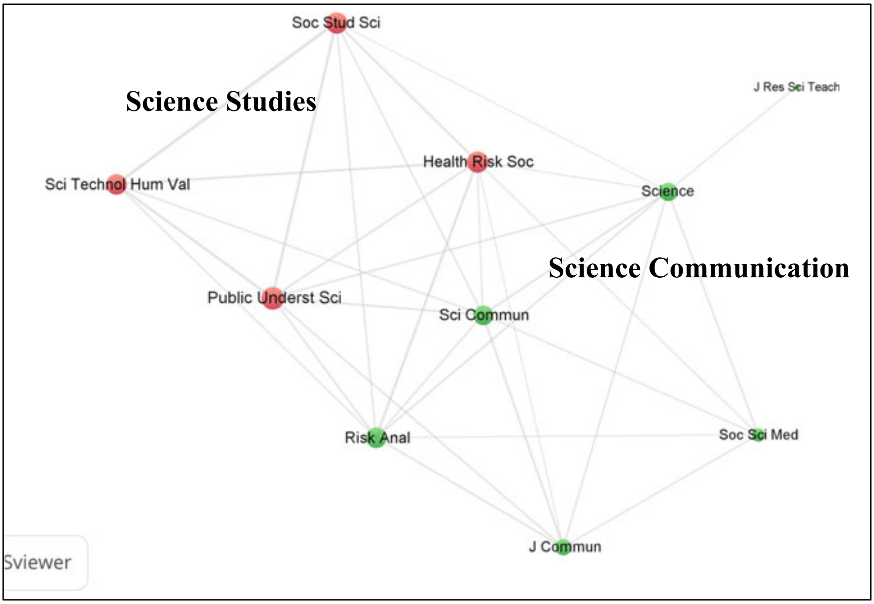

Fig. 2.3 Bibliographic coupling among ten journals cited above the 1%-level in 67 papers published in *Public Understanding of Science* in 2011; cosine > 0.1; $Q = 0.1373$

specific literatures. These bibliographic couplings of references (mapped in Fig. 2.3) are instantiations in a specific year (2011) of the latent and self-organizing structures of the relevant disciplines shown in Fig. 2.2.

Figure 2.4 shows the substantive variation in terms of the topics under study in the same 67 papers. One can further enrich the map by adding the co-author network, their institutional affiliations, national and international collaborations, etc. The tools of social and semantic network analysis enable us to study the dynamics in the various dimensions of the sciences in considerable detail (e.g., Leydesdorff et al., 2008; Scharnhorst et al., 2012).

2.5 Concluding Remarks

The shaping of the context of mediation has followed the historical development of communication technologies. For example, the printing press made the development of the sciences possible from the seventeenth to the twentieth century. The late twentieth century has witnessed the emergence of the internet as a new (global) communication technology. New media changed scientific practices both at the level of the context of discovery and the context of justification (e.g., Heimeriks & Vasileiadou, 2008). New patterns of communication can be expected to change the codes of

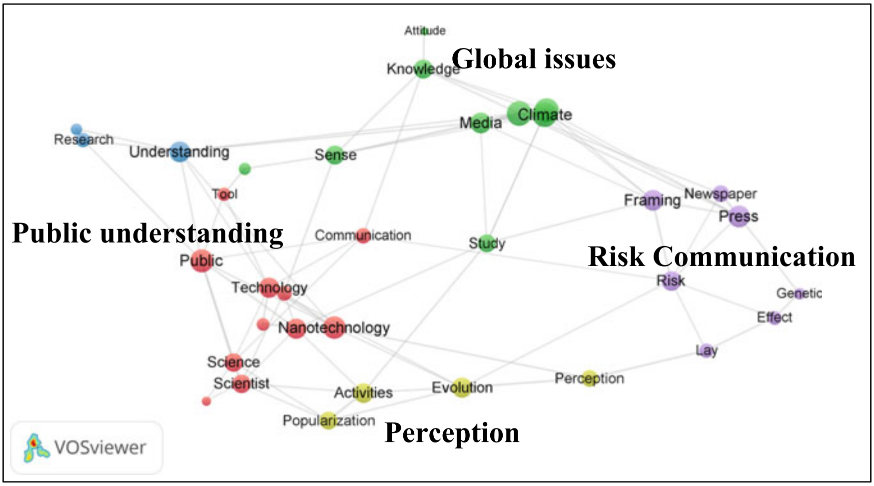

Fig. 2.4 Topical network indicated by 34 words occurring more than twice in the titles of 64 documents (Three more documents (Editorials) have no title words.) published in *Public Understanding of Science* during 2011; cosine > 0.2; 5 clusters indicated with $Q = 0.449$

communication albeit probably with a delay (Larivière et al., 2008). The various dynamics feedback on one another.

Since the 1970s, listservs and email have become communication tools changing laboratory life. The very process of science has become intensively embedded in literature and communication. The flows of communication and literature were increased by orders of magnitude (Hull et al., 2008). More recently, the development of Google Scholar (2004) has made conference proceedings, open journals, portions of books, and personal and collections of manuscripts accessible on the internet. Other major technological developments include real-time communication among collaborating scientists, shared databases of references, and webinar tools. One can expect these communication technologies to be further developed in as yet unknown directions (Chap. 9).

The mapping of the sciences using scientometric tools makes it possible to visualize the evolution of the sciences as networks (Börner, 2010). This "communication turn" adds the social-science perspective of communication and information studies to the "linguistic turn" in the philosophy of science (Rorty, 1962). The language usage under study can be coded and differentiated into specific jargons. By analyzing the sciences as communication systems in which knowledge is constructed, one obtains both a rich conceptualization and the possibility to proceed to measurement. The communicative mediation reflects the evolutionary dynamics. The study of these communication dynamics thus opens the philosophy of science to empirical operationalizations other than thick descriptions. Hypotheses about scientific developments can be formulated, and confirmed or rejected on statistical grounds (e.g., Giere, 1988; Small, 2020).

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