Chapter 68
Capturing the Dynamics of Science in Science Education

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The broad aim of science education is scientific literacy (i.e. the forms of knowing the students will require as citizens in a scientifically and technologically sophisticated society of tomorrow). In contemporary knowledge societies, the production of scientific knowledge is unprecedented in scale and becoming increasingly reflexive, transdisciplinary and heterogeneous. This inherently increasing dynamics of science faces us with the problem that the level of scientific literacy with which students are being equipped within schools is getting out of pace with the level of scientific knowledge that is produced and applied in other parts of society.

At the heart of the problem is the question of what we mean by scientific literacy. Indeed, what scientific literacy is taken to be depends very much on the conceptions of science discursively associated with it. If scientific literacy is defined in terms that fail to grasp the dynamics of science, then students cannot be properly equipped with the knowledge that they will require as citizens in such societies. This raises the question of whether and how definitions of scientific literacy appropriate the dynamics of science. This chapter briefly reviews the science education research literature related to these questions.

This chapter takes three turns. First, a contemporary framework from the social studies of science is laid out in order to grasp the dynamics of science in contemporary knowledge societies. Next, drawing on this theoretical frame, the science education research literature is reviewed, with the aim of understanding how definitions of scientific literacy address the dynamics of science. This review illustrates that the dynamics of science are appropriated by a definition of scientific literacy as an emergent feature of collective human activity. Finally, the implications of this claim for science education are discussed. It is argued that scientific literacy understood as a collective entity requires a science education in which the learners' agency is central.

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Capturing the Dynamics of Science

The dynamics of science is a rather young research topic. Sparked by a sociological turn in the philosophy of science introduced by Thomas Kuhn (1970), researchers became interested in what scientists actually *do* and how their actions shape scientific knowledge. Since the late 1970s, an increasing number of studies were setup with the aim of monitoring how scientists go about their everyday work in laboratories, at conferences and in the field. Bruno Latour and Steve Woolgar (1986) were among the first social scientists to produce ethnographies of the manifold and complex ways in which natural scientists produce scientific knowledge. Ethnographies like these undermined the possibility of any logical reconstruction of the processes that legitimise scientific theories that philosophers of science, such as the logical positivists and Karl Popper (1959), were after. Put shortly, it appeared that the 'scientific method' is a myth. Simultaneously, scholars in this discipline developed sociocultural frameworks that allowed a better understanding of the dynamics of science than a logical reconstruction based on ready-made science.

One common framework for understanding the dynamics of science is actor-network theory, which resulted from the work of Bruno Latour (1987) and Michel Callon (1991) in their attempts to reveal the dynamics of the infrastructure that constitutes the often-static accounts of scientific and technological achievements. They recognised that science-in-the-making develops dynamically in time and space and cannot be described by temporally and spatially static elements that are discursively associated with the ready-made science that one might find, for example, in science textbooks. These static elements commonly reduce accounts of scientific and technological artefacts to categories that are natural (the things 'out there in the natural reality' discovered by scientists), social (the 'heroic' scientists) or discursive (formulae such as $E = mc^2$ and other texts that can be commonly found in science textbooks). Hence, to describe how science-in-the-making occurs, they developed a non-reductionistic approach by taking into account simultaneously all categories (social, natural, discursive) that were hitherto considered independently. Pivotal in this approach is the idea of actor-networks, which merge the two terms of actor and network which usually are featured as opposites in the social sciences. However, according to Callon:

> …it is not just another attempt to show the artificial or dialectical nature of these classical oppositions. On the contrary, its purpose is to show how they are constructed and to provide tools for analyzing that process. One of the core assumptions of ANT is that what the social sciences usually call 'society' is an ongoing achievement. ANT is an attempt to provide analytical tools for explaining the very process by which society is constantly reconfigured. What distinguishes it from other constructivist approaches is its explanation of society in the making, in which science and technology play a key part. (Callon 2001, p. 62)

Hence, focusing on the constant reconfiguration of society – the society-in-the-making – allows us to understand the dynamics of science and technology as playing a key role. A characteristic for this holistic approach is the absence of a presumed boundary between nature and culture. Thus, there is the premise of symmetry between human actors and nonhuman participants (artefacts, 'natural' entities) in

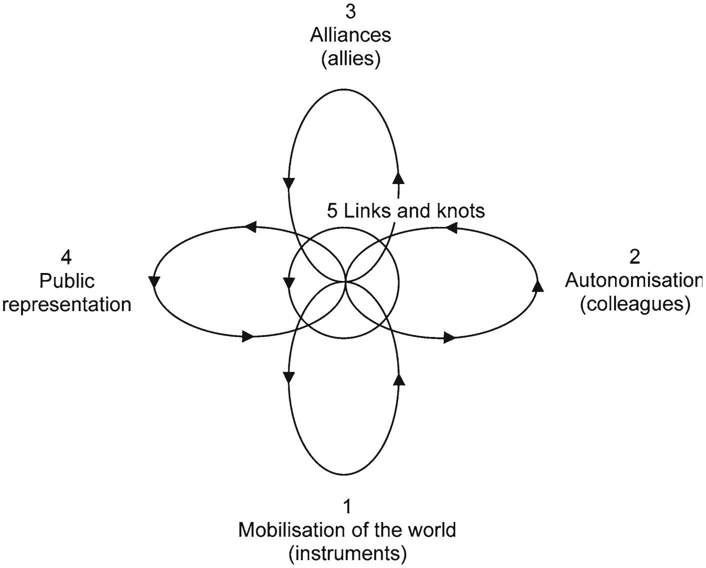

Fig. 68.1 Actor-network theory-based model of the dynamics of science (after Latour 1999)

the way in which they act and are acted upon in actor-networks. For instance, both Einstein and $E = mc^2$ can be considered actants in the developing actor-networks that constitute reconfigurations of society.

One implication of actor-network theory is that the dynamics of science cannot be appropriated by focusing only on the scientific concepts and the 'context' in which they are used, because this would again result in a reduction of scientific and technological artefacts to either natural, social or discursive categories. Models of the dynamics of science based on actor-network theory overcome this reduction by showing how such conceptual and contextual elements result from the flow of human actors and nonhuman participants through actor-networks developing over time. For capturing the dynamics of science, at least five loops have to be taken into account simultaneously (Fig. 68.1).

Mobilisation of the world, the first loop in Fig. 68.1, refers to 'all the means by which nonhumans are progressively loaded into the discourse' (Latour 1999, p. 99). It is the logistics of science, dealing with surveys, instruments and equipment, by which the world is converted into inferences, starting at sites and aiming at transportation towards laboratories where the world is assembled and contained into increasingly encompassing collections and representations. The second loop represents how a researcher finds colleagues and is called autonomisation, which 'concerns the way in which a discipline, a profession, a clique, or an "invisible college" becomes independent and forms its own criteria of evaluation and relevance' (pp. 101–102). This loop thus includes the institutionalising of scientific enterprises and the inherent formation of what Karin Knorr Cetina (1999) calls 'epistemic cultures'.

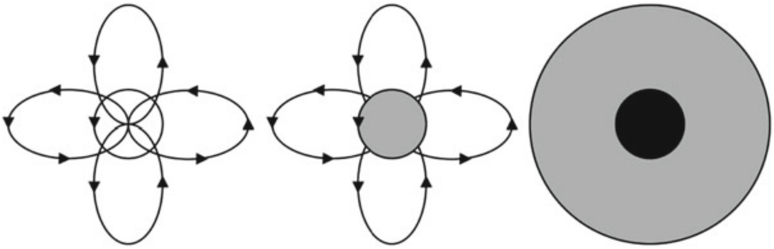

Fig. 68.2 Decreasing appropriation of the dynamics of science (after Latour 1999)

The third loop in Fig. 68.1 – alliances – shows that no scientific enterprise is completely autonomous, but is dependent on allies. It concerns institutions, such as the military, industry and government, which are interested in physics, chemistry and political science, respectively. The fourth loop is public representation, which is the process by which novel objects of science become massively socialised and part of the discourse in the public domain. For instance, whereas the word 'atom' was once a particular name used mainly in physic laboratories, it is today part of daily speech. Finally, the circle in the centre, the fifth loop in Fig. 68.1, refers to the conceptual elements, but this is envisioned as a series of links and knots that keep the other loops tightly together rather than the 'conceptual content'. This is not to say that it is less 'hard' than scientific concepts, but 'this hardness is not that of a pit inside soft flesh of a peach. It is that of a very tight knot at the center of a net. It is hard because it has to hold so many heterogeneous resources together' (p. 106). Collectively, the five loops in Fig. 68.1 are what Latour (1999) calls metaphorically the science's blood flow for which the fifth loop functions as the heart – it keeps the other loops running. If there were no fifth loop, the other four would die off at once. As such, the concepts of science have a different topology: 'The content of science is not something contained; it is itself a container' (p. 108).

Actor-network theory allows us to understand how a strong focus on the conceptual content of science easily leads to a static, canonical model of science that misappropriates its dynamics (Fig. 68.2). If the links and knots (left) are excised from the other four loops in Fig. 68.2, it will be transformed in a core (middle). The other four now-disconnected loops form a sort of 'context' of no relevance for defining the inner core. The result is a static conceptual content encompassed by an opaque 'context' in which the loops cannot be distinguished anymore (right) in Fig. 68.2.

This brief introduction in actor-network theory shows that conceptions of scientific literacy that appropriate the dynamics of science are those that provide the tools to exemplify conceptual elements as links and knots, that is, as containers and not as something contained. In addition, such conceptions should account for ways in which the links and knots hold together dynamic loops such as mobilisation of the world, autonomisation, alliances and public representation.

Definitions of Scientific Literacy and the Dynamics of Science

Since its emergence in the 1950s, the concept of scientific literacy has always been hard to define. However, within the many different definitions in the research literature, three trends can be distinguished that are each still present today. In what follows, each of these trends is reviewed to clarify how definitions of scientific literacy appropriate the dynamics of science.

Scientific Literacy as the Aim of Science Education

The concept of scientific literacy has always been associated with the aims of science education. Paul DeHart Hurd (1958) was among the first who introduced the concept in the North American academic debate on curriculum reform. At the time, there was much confusion about the purpose of science education. World War II had brought concerns about catastrophic uses of science, such as the atomic bomb. In addition, the launch of the Sputnik which showed the Russians' scientific leap forward raised awareness of the role of science in safeguarding national security. As a result, the aim of science education was more than only contributing to an increased output of highly specialised scientists and engineers. In addition, every educated person had to be literate in science because society required citizens who could appreciate and understand what scientists and engineers were doing.

Despite concerns about the accountability of science to the society, scientific literacy was usually articulated as the attribution of scientific 'content' to the student. In addition, knowledge was commonly defined in terms of cognitive objectives, which limited the theorising of such scientific 'content'. The work of Lawrence Gabel (1976) is representative of early research on scientific literacy. In order to bring coherence to the many different definitions of scientific literacy, the literature was reviewed in terms of Benjamin Bloom's *Taxonomy of Educational Objectives* (1956). This kind of work was influential. For three decades after the birth of the concept, definitions of scientific literacy were almost exclusively in terms of attributing particular science content to the individual. Even today, major curriculum reform documents such as *Benchmarks for Science Literacy* (AAAS 1993) and the *National Science Education Standards* (NRC 1996), as well as their seminal predecessor, *Science for All Americans* (Jim Rutherford and Andrew Ahlgren 1989), treat scientific literacy by and large in terms of the scientific content that students are supposed to learn and know.

Regarding the appropriation of the dynamics of science, it is important to distinguish between scientific literacy, as a concept referring to the aims of science education in terms of scientific content, and scientific literacy in terms of knowing and learning. For instance, in a recent review of George DeBoer (2000, p. 592, emphasis added) scientific literacy is defined in terms of nine distinct aims of science teaching, of which one reads as follows: 'Science classes should give students the *knowledge* and *skills* that are useful in the world of work and that will enhance their long term employment prospects in a world where science and technology play such a large role'. Aims like these can be found repeatedly in major curriculum reform documents. However, aims like the above do not make clear exactly what will change when a science class gives students 'knowledge' and 'skills'. In other words, such definitions do not articulate the nature of the cognitive entity that is, for instance, useful in the world of work and that will enhance students' employment prospects in a scientifically and technologically sophisticated world. Accordingly, such definitions blur how scientific literacy appropriates the dynamics of science, despite the explicit referents to the latter. That is, although the previously-mentioned definition of scientific literacy refers to the alliance between science and the world of work, it does not make clear how this aim exactly contributes to understanding this aspect of the dynamics of science. Indeed, having the knowledge and skills that are useful in the world of work does not guarantee any knowledge of how the practice of professionals plays into the dynamics of science. Evidentially, this definition of scientific literacy includes a focus on science content that overshadows its nature as the knots and links pertaining to the dynamics of science (see Fig. 68.2). Hence scientific literacy defined in terms of content-based aims of science education does not appropriate the dynamics of science. For such an appropriation, scientific literacy should be defined in terms of what it means to know and to learn.

Scientific Literacy as Individually Constructed Knowledge

During the 1980s, science educators started to explicate in more detail what the concept of scientific literacy meant in terms of knowing and learning. This had to do with the emergence of constructivism as a dominant framework in science education research. As a result, researchers attempted to illustrate how knowledge is *constructed* in the process leading to increased scientific literacy. For instance, *Science for All Americans* explicitly refers to this process: 'People have to construct their own meaning regardless of how clearly teachers or books tell them things. Mostly, a person does this by connecting new information and concepts to what he or she already believes' (Rutherford and Ahlgren 1989, p. 198). Nevertheless, definitions of scientific literacy in terms of the aims of science education that emphasise scientific content were still dominant. Therefore, Piagetian versions of constructivism (1957) were applied to define scientific literacy in terms of what it meant to know. The resulting curriculum reform documents focused on knowledge as individual cognitive entities, which 'at least as exemplified in science education research, tend to assume that the teaching and learning process is directed toward producing students who, through their own activity, come to share established scientific knowledge' (Eisenhart et al. 1996, p. 278). Accordingly, a balance was maintained between established but implicit conceptions of knowledge in terms of scientific content and then-popular and explicitly adopted conceptions of learning and knowing. Scientific literacy was not only defined in terms of individually constructed knowledge, but also in terms of more or less static scientific content 'possessed' by individuals.

Regarding the appropriation of the dynamics of science, such a perspective is problematic in at least two ways.

The first problem is that scientific literacy, despite being the result of a construction, is still defined as scientific content that can be contained by individuals. Inherently this perspective on knowledge still overshadows the conceptual content of science as knots and ties, that is, as containers of alliances, instruments, colleagues and other such elements that collectively make up the dynamics of science (see Fig. 68.2). Therefore, such a perspective on scientific literacy contributes to a context-concept dichotomy that is at odds with appropriation of the dynamics of science.

The second problem is that scientific literacy is not only defined as scientific content that can be contained by individuals, but also refers to scientific content as established and hence rather static scientific knowledge. This emphasis on scientific knowledge as a static and established entity also overshadows the content of science as containers of other flows that make up the dynamics of science (see Fig. 68.2). In addition, such an emphasis has led Morris Shamos (1995) to conclude that scientific literacy simply cannot be present among non-scientists. He argued that established scientific knowledge is too complex to be mastered by everyone, *just because it is scientific knowledge*. The desired level of scientific literacy required for mastering this knowledge, which he called 'true scientific literacy', is such that 'the individual actually knows something about the overall scientific enterprise' (Shamos 1995, p. 89). According to Shamos, this level is inaccessible to the majority of the citizenry. Scientific literacy defined in terms of scientific content is thus at odds with the idea of scientific literacy as prerequisite for *all* citizens in a scientifically sophisticated society. These paradoxical consequences of defining scientific literacy in terms of individual and static conceptions of knowledge have led science educators to rethink the concept.

Scientific Literacy as an Emergent Feature of Collective Human Activity

In the 1990s, Margaret Eisenhart, Elizabeth Finkel and Scott Marion started to rethink the concept of scientific literacy by starting from its broad aim of 'producing citizens who can use science responsibly and including more people in science' (Eisenhart et al. 1996, p. 268). A fundamental incommensurability was observed with scientific literacy defined in terms of scientific content. Specifically, there was doubt that the individual 'acquisition' of scientific content would lead to a citizenry who will use science responsibly in their daily lives or profession.

One important argument against this assumption draws on studies of speech practices inside and outside of schools. Such studies suggest that academic science discourse privileged in school science actually might discourage socially helpful and responsible uses of science in situations that students could encounter in daily life and future professions. In addition, inherent to conventions of scientific discourse is the privileging of particular voices (Eisenhart and Finkel 1998). Relationships exist between knowledge and the power structures that privilege the particular voices and hands who articulate, construct and thus constitute such knowledge. Framing scientific literacy in terms of scientific concepts and methods thus facilitates speech genres and modes of action that are constitutive for and preferred by conventional science. Accordingly, the privileged way of knowing and doing is the common scientists' way, which largely exhibits white middle-class and male epistemologies. Minorities and women are therefore often discouraged from doing science or from moving into science careers.

Another argument against the assumption that individual 'acquisition' of science is congruent with the broad aim of scientific literacy is provided by Wolff-Michael Roth and Angela Calabrese Barton (2004). They argued that the specialised knowledge that is found in curriculum reform documents is both inaccessible by direct experience and irrelevant in the majority of people's daily lives. Also, there is little evidence that knowing school-like facts and basic skills contributes anything to competent functioning in the everyday world. On the contrary, ample evidence from studies of the use of mathematics in daily life suggests that there is no relationship between what is taught in schools and levels of performance in everyday mathematical tasks.

In other words, there is no reason to believe that the individual 'acquisition' of scientific content leads to the citizenry using science responsibly in their daily lives or professions. In this regard, science educators rethought conceptions of knowledge in order to define scientific literacy in a way that would be congruent with its broad aims.

As discussed in the previous section, the dominant focus on knowledge as an individual cognitive entity is rooted in particular readings of constructivism. Such frameworks fail to emphasise the wider activities associated with school science (such as schooling, science and work) which go beyond the individual. To overcome this limitation, therefore, scientific literacy was rethought from cultural-historical frameworks that appropriate such wider activities. Thus, what 'constitutes "knowledge" at a given moment or across a range of situations is a matter of analysis, which has to take account of the motivations, interests, relations of power, goals and contingencies that shape the activity' (Roth 2003, p. 17). Hence the idea emerged that scientific literacy can be perceived as an emergent feature of collective human activity.

Human activity is composed of 'many, often dissimilar and contradictory elements, lives, experiences, and voices and discontinuous, fractured and non-linear relationships between these elements, lives, experiences, and voices' (Roth 2003, pp. 17–18). What ultimately counts as 'scientific literacy' can therefore only be understood by analysis of these systems, that is, by examining the manifold and interdependent means (speech, texts, tools, actions) by which knowledge is produced and hence distributed over and situated in collective human activity. 'Emergent', then, refers to the interdependent relationship in the evolving setting that, at certain points, exhibits specific characteristics such as scientific literacy.

From the perspective of collective human activity, knowledge is collective and distributed over the activity. For instance, in one case study of school science, students were asked by a local organisation to restore a pond located on their property that was in poor health, stagnant and smelly (Eisenhart et al. 1996). In response, they developed a restoration plan and this work required the students to situate their tasks in the local community, establish relationships with experts and community members beyond the school, and develop ways of talking and writing that were useful and persuasive in a real-world setting. Here, scientific literacy emerged as the students collectively cultivated understandings of scientific concepts and ideas that were both locally useful and technically sophisticated.

In another case study of science in a rural community, citizens interacted with scientists during an environment-oriented open-house event centred around a dispute over local water resources (Roth and Lee 2002). This case study showed that, collectively, more advanced forms of scientific literacy can be produced than for any individual (including scientists). For instance, the citizens questioned a scientist about the methodology that he used, which turned out to fall short for the problem at hand. Here, scientific literacy cannot be explained as individual, discrete and testable knowledge. In such terms, both citizens' questioning and scientists' inadequate responses would be understood as a lack of understanding of appropriate scientific methods. As collective activity, however, scientific literacy can be understood as an emergent feature of the collective human activity of both scientists and students. In this case, the scientist is not longer privileged as the one who defines what the scientifically literate citizen 'needs'. Nor is knowledge something that is 'used' by citizens in a scientifically sophisticated society. Rather, citizens and scientists collectively produce the scientific knowledge that is constitutive for the emerging scientific literacy which, in turn, contributes to a scientifically sophisticated society.

Definitions of scientific literacy that frame knowledge as collective human activity appropriate the dynamics of science in several respects. According to this frame, scientific content is not defined as something that is contained by individuals, but as tools in human activity. Because tools are dialectically linked with the wider activity in which they are used, they can be thought of as being inextricably bound up with and hence keeping together other aspects of activity, such as the human subjects using these tools, the communities in which they are used, and the specific rules that are associated with tool use. Hence, scientific content relationally contains the other elements of human activity rather than being fully contained by the individual human subject that is also part of this practice. In this way, scientific content is thought similarly to the knots and links that make up in part the dynamics of science (see Fig. 68.1). Moreover, when scientific content is understood dialectically as knots and links that keep together the other aspects of collective human activity, it can only be thought of as relational with the context which it shapes and by which it is shaped. Indeed, perceived from a perspective of knowledge as collective human activity, scientific content is part of this context. When scientific literacy is thought of as an emergent feature of collective human activity, it cannot overshadow the knots and ties that keep together alliances, instruments, colleagues and other such elements that collectively make up the dynamics of science (see Fig. 68.2).

Coda

Defined as an emergent feature of collective human activity, scientific literacy appropriates the dynamics of science because it provides the tools to exemplify conceptual elements as links and knots (i.e. containers) and not as something contained. In addition, it allows one to distinguish how the links and knots contain and hold together the dynamic aspects that shape and are shaped by the 'context' of science, such as instruments, autonomisation, alliances and public representation. How could we envision science education from this perspective?

Thinking in terms of activity implies that scientific literacy cannot be considered apart from the activities in which students engage. Hence scientific literacy emerges in those activities that bear considerable resemblance to the activities that produce scientific knowledge. Two examples of such activities in which students engaged have been illustrated previously. The key issue with respect to the emergence of scientific literacy is the extent to which students engage meaningfully in such activities and hence develop competent participation.

Currently, schooling does not give students many opportunities to develop competent participation in activities that bear considerable resemblance with the activities that produce scientific knowledge. This is because schooling activities are supposed to unfold in particular predetermined ways that lead students to 'mastering' specific scientific 'content'. Accordingly, in school science, scientific literacy is commonly defined in terms of scientific content that is supposed to be contained by individual students rather than a container that holds together the dynamic flows of science. Moreover, in terms of collective human activity, students are withheld from the agency by which they can exert the power over the elements that collectively determine how the activity unfolds. For instance, students are usually not allowed to participate in setting the goals and objects of their activities, choose tools, determine the division of labour or participate in constructing the rules. The result is that, rather than collectively becoming scientific literate, students become literate in meeting the aims of the schooling activity, namely, getting high grades. Students engage in a form of learning which Klaus Holzkamp (1993) has called *defensive learning* – a form of learning that has the function to avoid punishment.

In contrast, to engage meaningfully and hence develop competent participation in knowledge-producing activities in science, students should be given the agency to co-determine the way in which such activities unfold over time. In a science education envisioned from this perspective, the emerging scientific literacy appropriates the dynamics of science. Indeed, agency allows students to participate in setting the goals and objects of their activities, choose tools, determine the division of labour or construct the rules. In other words, it allows students to develop competent participation in keeping these activities running and to find allies, design instruments, mobilise the world and so on. Furthermore, agency allows students to develop and hence understand how particular elements of knowledge-producing activities in science, such as rules, objects and tools, are used as knots and links in holding together the dynamic flows of these activities. In short, agency over knowledge-producing activities in science allows students to experience collectively how ‘methods’, ‘instruments’ and ‘concepts’ emerge as knots and links containing the dynamic flows of science. In such a science education, students collectively learn to produce the knowledge that they will require as citizens in a scientifically and technologically sophisticated society of tomorrow.

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