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The Philosophical Works of Ludwik Fleck and Their Potential Meaning for Teaching and Learning Science

Marc Stuckey · Peter Heering · Rachel Mamlok-Naaman · Avi Hofstein · Ingo Eilks

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Abstract This paper discusses essential elements of the philosophical works of Ludwik Fleck (1896–1961) and their potential interpretation for the teaching and learning of science. In the early twentieth century, Fleck made substantial contributions to understanding the sociological character of the nature of science and explaining the embedding of science in society. His works have several parallels to the later and very popular work, The Structure of Scientific Revolutions, by Thomas S. Kuhn, although Kuhn only indirectly referred to the influence of Fleck on his own theories. Starting from a short review of the life of Ludwik Fleck, his philosophical work and its connections to Kuhn, this paper elaborates upon and illustrates how his theories can be considered for science education in order to provide learners with a better understanding of the nature of scientific endeavor and the bi-directional science-to-society links.

1 Introduction

Most citizens in the western world want to be informed about and/or be involved in socio-scientific decisions (European Commission 2010). This is why learning about the role of science in society is necessary to enable students to become future responsible citizens (Hofstein et al. 2011). A societal view in science education is aimed at teach students how to cope with life in the society in which they live and operate. Students should not only find their place in society but also learn how to actively participate in societal discourse concerning socio-scientific issues (SSI) (Sadler 2004; Roth and Lee 2004). The SSI movement in science education suggests that students should learn more comprehensively

M. Stuckey · I. Eilks (✉)
Department of Biology and Chemistry - Institute for Science Education, University of Bremen, Leobener Str. NW2, 28334 Bremen, Germany
e-mail: ingo.eilks@uni-bremen.de

P. Heering
Institute of mathematic, scientific and technical literacy, Section of physics, its didactics and its history, Europa-Universität Flensburg, Auf dem Campus 1, 24943 Flensburg, Germany

R. Mamlok-Naaman · A. Hofstein
Department of Science Teaching, The Weizmann Institute of Science, 76100 Rehovot, Israel

about the potentials and limitations of science and technology, and how both interact with society (Marks and Eilks 2009; Sadler 2011). This is important because nowadays advances in science occur very quickly and their effects on society are increasing (European Commission 2010). Relevant science teaching must, among other things, focus on understanding the nature of science and needs to include a societal dimension (Stuckey et al. 2013). But learning about the nature of science and about the interrelationship between science and society still seems to be largely unsuccessful in many countries (Hofstein et al. 2011; McComas 2004).

This paper focuses on a socio-philosophical framework outlining how science operates at a social level and provides ideas on how Fleck's ideas can also be interpreted concerning how science is embedded in and interacts with society. The framework is built around the philosophical ideas of the Polish-Jewish microbiologist Ludwik Fleck (1896–1961). In 1935 Fleck wrote his now-famous book *The Genesis and Development of a Scientific Fact*. At that time the Polish language had not expanded outside the borders of Poland, but German was one of the most commonly used scientific languages. Thus, Fleck decided to publish his book in German in order to achieve a broader impact (Graf and Mutter 2005). However, the Nazi takeover of Germany in 1933 made it impossible for him as a Jewish author to find a German publisher. However, in June 1935 the book was published in Switzerland, but its circulation was extremely low. Only 640 copies were printed and a mere 200 were sold. Reception of the book was mainly restricted to German-language medical journals, most of which viewed the book a historical case study in medicine (Trenn 1979).

Fleck's philosophical theories remained mainly unrecognized for several decades in the international philosophical scene (Leszczyńska 2009). However, today there is a broader acceptance of his ideas. This development was initiated by the publication of Thomas S. Kuhn's *The Structure of Scientific Revolutions* in 1962. Thomas Kuhn was known as one of the most influential philosophers of science. He argued about the role of education and teaching, and he influenced many science educators and philosophers, e.g., Allen (1998).[1] Kuhn mentioned the inspiring nature of Fleck's work in the preface of his book. This was the first internationally published reference to Fleck's work since the 1930s (Trenn 1979). With the positive reception of Kuhn's work worldwide, interest in Fleck's work increased. In the beginning of 1976 *The Genesis and Development of a Scientific Fact* was translated into English and was finally published three years later. Since then Fleck's work has progressively been acknowledged in sociological and philosophical papers. However, the reception of Ludwik Fleck's theories in science education still remains rare. For example, McComas' (1998) famous contribution to better understanding the Nature of Science only refers to Kuhn (1962). It could have mentioned many aspects presented by Fleck (1935/1980, 1979) as was suggested by Olesko (2006), who used a different focus, but it did not.

This paper presents an overview of the philosophical and epistemological works of Ludwik Fleck. It starts with a short review of his life, his philosophy and its relationship with the work by Thomas S. Kuhn. This paper elaborates on how Fleck's theories can inspire relevant science education that provides learners with a deeper understanding of the nature of scientific endeavor and the bi-directional links between science and society.

[1] See also DeBoer (1991), Hurd (1998), or Pushkin (1998).

2 The Life of Ludwik Fleck

Ludwik Fleck was born on July 11, 1896 in Lviv which now is located in modern Ukraine, and was raised in the Jewish community there. During this time Lviv was part of the Austrian-Hungarian monarchy. A more detailed description of Fleck's life can be found in Sady (2001, 2012). In 1914 he finished school and began studying medicine at the Jan Kazimierz University in Lviv the same year, specializing in the field of microbiology. After graduation he worked as a medical assistant for Rudolf Weigl, who was a specialist in typhus.

In 1922 Fleck finished his doctoral degree in general medicine and continued to work for Weigl for an additional year. Thereafter, Fleck was employed by the department of internal medicine and was the director of the bacteriological laboratory until 1925. Later he was the laboratory head for epidermal diseases in Lviv's general hospital. After a year in Vienna, Fleck became director of the bacteriological laboratory for a local health insurance company in 1928. During this period Fleck began to focus on philosophy and epistemology. In 1935 he published his seminal philosophical publication, *The Genesis and Development of a Scientific Fact* (original title: *Die Entstehung und Entwicklung einer wissenschaftlichen Tatsache*). Fleck established his private laboratory the same year, specializing in research on Fleck-fever, syphilis, tuberculosis, and pemphigus vulgaris.

Lviv was occupied by the Soviet Union at the beginning of World War II. Fleck was appointed lecturer and head of the microbiology research department at the Ukrainian medical center. With the advent of the occupation of Lviv by German troops in 1941, Fleck and his family were incarcerated in the Jewish ghetto of Lviv. Two years later they were sent to the concentration camp at Auschwitz, then later to Buchenwald. The Nazi regime also tried to benefit from Fleck's expertise in bacteriology. He was forced to work on developing a typhus vaccine for the German army. However, Fleck and other Jewish physicians created an ineffective vaccine in huge quantities, a fact which completely escaped detection by the Nazis.

After the war Lviv became part of the Soviet Union. Fleck and his wife went to Lublin, Poland, where he became head of the department of medical microbiology. Fleck's decision to focus his research on medicine appreciably weakened his efforts to intensify his work on epistemology. In 1946 Fleck finished his habilitation and a year later he became a well-recognized professor of the autonomous Academy of Medicine in Wroclaw. Three years later Fleck was appointed a full professor. He worked in Warsaw, became a member of the Polish Academy of Sciences, and earned many rewards for his outstanding publications. After suffering a heart attack in 1956, Fleck decided to spend the rest of his life with his remaining family in Israel. He emigrated to Israel, where his son had already been living for many years. He continued his research in different laboratories in Ness-Ziona, south of Tel Aviv, and at the Hebrew University of Jerusalem. Unfortunately, later Fleck contracted Hodgkin's disease and died of a second heart attack in 1961.

One year after his death, Fleck was mentioned by Thomas S. Kuhn in the preface of his book, *The Structure of Scientific Revolutions* (Kuhn 1962). Kuhn acknowledged Flecks' epistemology from *Genesis and Development of a Scientific Fact* as an inspiration. However, he did not make further references to Fleck's theories anywhere in the book. Even Kuhn's preface of the 1979 English-language translation of *The Genesis and Development of a Scientific Fact* (Fleck 1979) does not address the question further. Kuhn says that he himself is uncertain which elements he (possibly unconsciously) adopted from Fleck's work, since he read Fleck's book 10 years before his book *The Structure of Scientific Revolutions* was published.

3 Central Ideas of Fleck's Philosophy Relevant to Science Education

Fleck was a medical researcher, but he was also interested in philosophy and epistemology. His curiosity in philosophy emerged in the 1920s when he became interested in publications by different philosophers and sociologists. It was at this time that the "Lviv-Warsaw school" of philosophy emerged, which was strongly influenced by the Vienna Circle. Fleck participated in many discussions of this group regularly and in 1927 he published his first epistemological article (Fleck 1935/1980). In *Crisis of Reality* Fleck (1927/1986) began to generalize specific observations and philosophical ideas from medical research into a more general scientific and philosophical perspective. These early ideas in the 1930s resulted in the book *Genesis and Development of a Scientific Fact* (Fleck 1935/1980).

Genesis and Development of a Scientific Fact attempts to analyze the social and historical developments in German medical research in the late 1920s and early 1930s. Fleck suggested an explanation of both how changes in scientific knowledge occur and how the scientific community behaves (Bonah 2002). Fleck's monograph discusses the medical understanding of syphilis as well as the development of a standardized test for its detection (the Wassermann reaction) as examples to elaborate his epistemological concept.

The central terms in Fleck's concept are the ideas of *thought style* (German: Denkstil) and *thought collective* (German: Denkkollektiv). A *thought collective* can be defined as "a community of persons mutually exchanging ideas or maintaining intellectual interaction […]" (Fleck 1979, p. 39). According to Fleck, the *thought collective* is the carrier of a *thought style*. This means that *thought styles* do not exist by themselves but instead require the *thought collective*. Some authors view this idea as the origin of the sociological understanding of science (Baldamus 1979). A collective cannot be formed intentionally. It is created in the process of discourse taking place without individuals necessarily being aware of its formation. This means that individuals can be both (1) unaware of their participation in a *thought collective* and (2) unaware of the role that is played in the related *thought style* in their perceptions and understanding of phenomena.

The *thought style* is defined as "directed perception, with corresponding mental and objective assimilation of what has been so perceived" (Fleck 1979, p. 99). Yet individuals are not always able to decide what is to be observed, because their ability to perceive is limited by their *thought style*. Since the *thought style* does not exist on an individual basis, scientific observations also do not take place only on an individual basis. Consequently, there are "three factors involved in cognition—the individual, the collective, and objective reality (that which is to be known) […]" (Fleck 1979, p. 40). Accordingly, Fleck is correct in pointing out that "[t]ruth is not 'relative' and certainly not 'subjective' in the popular sense of the word" (Fleck 1979, p. 100). In this respect, Fleck illustrates his understanding by clarifying that

> One can never say that the same thought is true for A and false for B. If A and B belong to the same thought collective, the thought will be either true or false for both. But if they belong to different thought collectives, it will just not be the same thought! […] Truth is not a convention, but rather (1) in historical perspective, an event in the history of thought, (2) in its contemporary context, stylized thought constraint. (Fleck 1979, p. 100)

The *thought style* does not just affect the cognitive register of the individual. The individual sees through the eyes of the collective, since seeing is not just a physiological aspect but also includes cognitive activities (Fleck 1947 as translated in Cohen and Schnelle 1986). Consequently, observation is affected by one's *thought style,* because one can only perceive what matches the reference frame created by it. Fleck uses the term

"Gestaltsehen" in this respect. This term suggests that the "Gestalt" per se does not exist but instead is formed in the process of seeing. This idea has many parallels to the idea of constructivist learning. Consequently, according to Fleck,

> […] the statement, 'someone recognizes something', demands some such supplement as 'on the basis of a certain fund of knowledge', or, better, 'as a member of a certain cultural environment', and, best, 'in a particular thought style, in a particular thought collective'. (Fleck 1979, p. 39)

This description implies that objective observation is not possible, since the observer is only able to perceive information through the filter of his or her *thought style*. Thus, the *thought style* (and also the *thought collective* as its carrier) plays an important role in the genesis and development of scientific knowledge. From this discussion the title of the book becomes clear. In Fleck's theory a scientific fact does not exist per se; it originates and is developed within the *thought collective* and is based on the *thought style*. This view does not concern its existence as such, but instead, its recognition by science. This was explicitly expressed by Olesko (2006, p. 873) that "[…] facts are not born or discovered, but are social constructions arising from a collective actively engaged in the creation and maintenance of a thought style."

From Olesko's perspective, it is evident that Fleck also addresses the process of becoming a member of a *thought collective*, how this collective is structured, and how it interacts with other thought collectives. In the formation of a *thought collective* Fleck particularly emphasizes the role of education:

> Every didactic introduction is therefore literally a 'leading into'. […] The initiation into any thought style, which also includes the introduction to science, is epistemologically analogous to the initiations we know from ethnology and the history of civilization. Their effect is not merely formal. The Holy Ghost as it were descends upon the novice, who will now be able to see what has hitherto been invisible to him. (Fleck 1979, p. 104)

The explicit discussion of the role of educational procedures was unusual for epistemological works in Fleck's time and may be seen as another unique characteristic of Fleck's work. This also becomes clearer in the analysis Fleck made with respect to scientific knowledge. According to him, we can distinguish between different forms of knowledge: On the one hand, there is journal and handbook knowledge for specialists and general experts in a certain *thought collective*. On the other hand, there is textbook knowledge that is related to the process of introducing novices to the *thought collective* (Olesko 2006).

In this sense, the *thought collective* itself is a heterogeneous group: Fleck distinguishes between general experts and specialists in the field of research. The latter actually produce new knowledge. Fleck refers to their knowledge as journal science, since new knowledge in science is typically presented, criticized, and discussed in scientific journals. A specialist's knowledge is still flexible and contains much argumentation and proofs in its presentation.

The general experts' knowledge is referred to as *vademecum* science. This knowledge appears to be more persistent and less flexible than journal science, yet it is still characterized by proofs. This general expert's knowledge is expressed as handbook science, since scientific handbooks are typical accumulators of knowledge, tested and accepted by the scientific community in a certain field. Both the specialists and the general experts form the so-called esoteric circle of the *thought collective*. More distant to this research is the exoteric circle, people who can be characterized as "educated amateurs" with respect to a particular field of knowledge (Fleck 1979, p. 111). The knowledge of the exoteric circle is characterized as popular science, which is produced for the public sphere (Olesko 2006).

This knowledge is more “pellucid and facile; at the same time, thought-constrained proofs disappear, it becomes even more apodictic” (Fleck 1979, p. 115).

Although individuals may belong to only one esoteric circle of a professional scientific *thought collective*, they can belong to several other *thought collectives* simultaneously (e.g., concerning political activities, religious beliefs, or leisure interests). Consequently, individuals are as different from one another as the combinations of collectives to which they belong. This sometimes makes communication difficult, if the people interacting come from two totally different sets of *thought collectives*. However, this fact also forms the basis of possible innovations or modifications of knowledge and criteria to identify knowledge within one’s own collective. Influences from members of other collectives and transfer elements between *thought styles* both have the ability to initiate new developments and changes (Fleck 1979).

Fleck’s understanding of the different *thought collectives* as well as their inner structures and interrelations has many implications. It suggests that every scientific endeavor and the path to its acceptance in science takes place within the esoteric circle of a specific *thought collective* representing one field of scientific research. In Fleck’s line of thinking, the *thought collective* changes its *thought style* by integrating new findings or theories. However, the work in the esoteric circle is not independent of its exoteric circle, not even from persons who are more than just educated amateurs. Transfer of knowledge into and reception by exoteric domains is necessary whenever a society is asked to decide about the ethical and societal implications of research and its findings. Therefore, the information must be transferred from the esoteric core to the exoteric circle and possibly even beyond. Along the way, information needs to be selected, simplified, and either described or illustrated to achieve comprehensibility with the help of the expertise (*thought styles*) of the author (Bauer 2009). A selection, simplification, and critical reception gradient exists for any information being transferred from the esoteric core to the exoteric circle and beyond (Fleck 1935/1980). But the influence also works the other way around. Exoteric domains influence the esoteric circle in a specific field of science by means of perceiving the scientific endeavor, through political decisions about the ethical limitations of research, and by funding.

As mentioned before, widespread recognition of *Genesis and Development of a Scientific Fact* took place many years after its publication. The monograph initially received an “astonishingly broad reception, which was cut off through the Nazi regime” (translated from Werner and Zittel 2011, p. 11), although its dissemination was initially limited to a relatively small circle of medical journals. It then took almost three decades until Kuhn’s (1962) work reintroduced these ideas to people other than the German-speaking countries (Trenn 1979). Probably more important for the current importance of Fleck’s work, however, were the English-language translation (Fleck 1979) and a German re-publishing of his main monograph in 1980. Additionally, some of his articles were also translated into English (Cohen and Schnelle 1986) and republished in German (Fleck 1983). Because the acknowledgement of his insights came so late, Fleck has also been called the ‘Gregor Mendel of the history and philosophy of science’ (Bonah 2002, p. 187). At the same time, Fleck was also listed among the ‘classical’ figures of both epistemology and the social history of science, a position comparable to Karl Popper or Robert K. Merton (Bonah 2002; Howard 2009).

Since 1979 there has been much acknowledgement of the highly inspiring nature of Fleck’s work. Nevertheless, his work has also been criticized. For example, other authors disagreed with Fleck’s collectivist interpretation of the term style, which was understood by them to describe individual styles of scientists (Fruton 2002), an aspect often linked to the existence of national or regional styles (Gayon 1999).[2] Moreover, Fleck has been identified as a precursor of constructivist theories in the philosophy of science (see for example, Bunge 1991; Freudenthal and Löwy 1988; Harwood 1986). In particular, Bunge is very critical in his discussion of Fleck's work as well as the sociology of science as a whole. Without going into details, it can be said that Bunge has two major criticisms: the incommensurability of collective (not necessarily in the Fleckian notion) thoughts with the individual, and the idea that all scientific facts are pure constructs by the collective. With respect to the first criticism, it can be argued (see for example, Harwood 1986) that according to Fleck the individual is a member in a variety of thought collectives. When combining these collectives, the individual is able to come to an understanding or gain insights, which are unique and can only be developed by this particular individual.

The conflict between realism and constructivism appears to be at the core of the criticism that has been raised against Fleck's conception. Yet most criticisms (as well as most constructivists) go well beyond Fleck's conceptual understanding. In the last two decades, constructivism (in particular, the strong program) has been discussed very critically (Bunge 1991).[3] Although Fleck is considered to be a historical reference for constructivist theories and is associated with the new sociology of sciences, this criticism may also apply to his work. However, one can actually question whether Fleck would have subscribed to the radical understanding that can be found in approaches such as "sociology of scientific knowledge" or radical constructivism. As Borck (2004, p. 457) has pointed out: "Fleck located the origin of a scientific fact in the mute but tangible resistance of the material world for which he coined the insightful notion of the *Widerstandsaviso*." The discussion by Harwood (1986) stresses, on the one hand, the relevance of Fleck's work, yet, on the other hand, it is also critical and points out that claims to assign more than historical importance to Fleck's writings have not been adequately justified (see Harwood 1986, p. 183; for a different approach, see for example, Borck 2004). However, Harwood also states the need to "refashion the fragmentary concepts in his [Fleck's] work to a full-blown theory" (Harwood 1986, p. 186). Even though Harwood's position appears to be questionable, it is evident that the discussion on constructivism is foremost not a discussion on Fleck's work. However, the critical reception of Fleck's theories was generally found in the discipline of philosophy rather than in the area of education.

In education, in general, and science education, in particular, there were only a few works that even referred to Fleck. When looking at the respective reception of Thomas Kuhn's *Structure of Scientific Revolutions* (Kuhn 1962) in the field of science education, this is no longer so surprising: Matthews (2004, 93ff.) observed that Kuhn was recognized in science education only belatedly. It is therefore not so surprising that an author who had been hardly recognized until well after Kuhn, did not gain so much attention in science education. Yet recently things are beginning to change. Olesko (2006), for example, emphasized the potential of Fleck's approach for studies on the history of science education. Likewise, Heering (2007) and others[4] suggested expanding Fleck's concept on understanding experimental practices in science and in science education. Buchdahl (1993)

[2] More detailed information can also be found in e.g., Harwood (1993), Nye (1993), Pyenson (2002), and Reingold (1991).

[3] Apart from Bunge (1991), see e.g., Matthews (2000), Slezak (1994a, b). Note that this discussion focuses mainly on constructivism in the philosophy of science and epistemology, and education is only affected when these theories are relevant to education. Constructivist educational theories can be distinguished from these approaches; for a very clear and comprehensive discussion of these differences and the related approaches, see Irzik (2000).

[4] See also Gaudilliere (2004), Heinicke and Heering (2013) and Maienschein (1991).

also proposed applying Fleck's work with respect to developing an educational syllabus covering both the teaching of science and learning about science in general. The latter idea was also suggested by Eilks et al. (2014), whereby Fleck's theory would be used to teach the relationship between science and society.

4 From Fleck to Kuhn, and from Kuhn to Fleck

The influence of Thomas S. Kuhn's (1962) book, *The Structure of Scientific Revolutions,* on the philosophy of science has been very large. His book was one of the most discussed books on the philosophy of science during the second half of the twentieth century. In the preface of his book, Kuhn noted that Flecks' monograph preempts many of his ideas, which were published 27 years after the *Genesis and Development of a Scientific Fact* appeared and just a year after Fleck died.

> That is the sort of random exploration that the Society of Fellows permits and only through it could I have encountered Ludwik Fleck's almost unknown monograph, Entstehung und Entwicklung einer wissenschaftlichen Tatsache (Basel, 1935), an essay that anticipates many of my own ideas […]. Fleck's work made me realize that those ideas might require [them] to be set in the sociology of the scientific community. Though readers will find few references to either these works or conversations below, I am indebted to them in more ways than I can now reconstruct or evaluate. (Kuhn 1962, p. IX)

This statement by Kuhn, which in his own words reveals Fleck's ideas in his later essay, is today discussed as quite ambivalent. Kuhn mentions Fleck (and his 'pre-work'). However, he claimed to have forgotten them when it came to writing the *Structure of Scientific Revolutions,* and for that reason he did not really credit Fleck in a more positive fashion in his book. In fact, he did not cite Fleck nor did he refer to some of the obvious parallels in Fleck's work and terminology during the course of his book (Baldamus 1979). From today's perspective it is difficult to say to what extent Kuhn felt that he was inspired by Fleck and whether this was a conscious or unconscious process. It seems that Kuhn knew that he had to credit Fleck, but maybe he considered his work to largely stem from Fleck's ideas. This is one case why during the last decade Fleck and Kuhn (and their ideas) have been compared by philosophers in many different ways (Babich 2003).[5]

Few of the articles published to date have discussed the great overlap between Fleck's and Kuhn's work. Winneke (1993), for example, describes the unmistakable similarity between Fleck's terms *thought style* and *thought collective* and Kuhn's *paradigm* and *scientific community*. But any attempt to equate *paradigm* and *thought style* or *scientific community* and *thought collective* seems to run immediately into difficulties. Fleck's term combines a huge variety of issues that are shared by a certain *thought collective*. This can be differentiated from Kuhn's perspective, which focuses more on the shared hard facts of scientific work. Another difference seems to lie in the central question upon which Kuhn and Fleck focus: Fleck addresses mainly questions concerning the generation of knowledge; in contrast, Kuhn addresses more aspects concerning the establishment of knowledge. Both processes can be described as being closely interconnected, yet also somehow they can be differentiated from one another.

Thus, many articles indicate both the important similarities but also the differences between Fleck and Kuhn (e.g., Mößner 2011). The similarity between Kuhn and Fleck depends on the development of scientific thinking and how science derives its knowledge.

[5] See also Egloff (2005), Mößner (2011), and Winneke (1993).

Both authors point out that knowledge is influenced by social components. Fleck and Kuhn also have similarities regarding their descriptions of scientists' behavior when they are confronted with abnormalities or counter-evidence. However, according to Egloff (2005), Kuhn's perspective on science differs from other societal areas. In contrast with Kuhn's view of science, Fleck suggest that science is embedded in society and culture, and can interact and be influenced by both of them. This can also be seen in Bunge's (1991) account, who points out that Kuhn was "a moderate global externalist historian […]" (p. 538), whereas Fleck is characterized as a "local radical externalist" (p. 540) and a constructivist.

In comparing the two epistemologies, Flecks' view is much milder than Kuhn's radical change of paradigms. This becomes clear when one considers the role of the early, initial ideas in a field of research. According to Kuhn, these ideas are derived from a pre-paradigmatic period; however, a field only becomes scientific after a first *paradigm* is established. From Kuhn's perspective, the random accumulation of ideas in a pre-paradigmatic period is not seen as scientific. This perception differs from Fleck's understanding of *pre-ideas*. Fleck gives much more attention and importance to these pre-ideas. The value of pre-ideas is not based on their logical content. In Fleck's understanding the pre-idea is relevant in its heuristic meaning with respect to the potential development of ideas within the thought collective. From the viewpoint of education, Fleck's pre-ideas and Kuhn's pre-paradigmatic system of knowledge (which is not scientific at this point) can be related to the constructivist learning idea of students' preconceptions. In doing so, the different values matter significantly, depending on the epistemological position of the educator. According to Fleck, the pre-idea is related to the genesis of knowledge, and bears at least some potential for cognitive development, although Fleck also stresses resistance to novelty in the field of education. Thus, Fleck emphasizes the role of education and training to keep the learner on track. Also, for Kuhn education seeks to overcome preconceptions. For him this would represent a dramatic conceptual change for the worse instead of cognitive development. From this point of view, Fleck's concept seems to be more constructivist than Kuhn's, both in terms of epistemology (Harwood 1986) as well as education.

Despite the differences between the conceptions of Fleck and Kuhn, both approaches also have similarities when it comes to the formation of scientists (Mößner 2011). As Matthews (2004, p. 96) pointed out, "learning, cognitive apprenticeships, and transmission of basic concepts and methodologies were important components of the establishment of a paradigm […]". Flecks approach in this respect is similar: novices are initiated into the field, and this initiation also serves as a means of stabilizing the *thought style*.[6] Consequently, both Fleck and Kuhn also discuss the role of science being represented in textbooks in seemingly comparable ways. Yet, as Brorson and Andersen show, this similarity is only superficial:

> In Kuhn's model, textbooks play a stabilizing role, embodying the accepted phenomenal world and transmitting it to new generations. […] Contrary to Kuhn's account, Fleck's account emphasizes the non-revolutionary change of the phenomenal world, which he claims is due to a continuous flux of thoughts and ideas. For Fleck, the phenomenal world is never a fixed world, but is continuously reshaped through circulation within and between the social strata and their literature. It is through this

[6] Remarkably, both Kuhn's and Fleck's description of learning seems not to be in agreement with the current theory of science education that corresponds to a constructivist (in the educational sense) understanding of learning. Yet, it should be understood that both descriptions discuss more the manner in which a professional formation takes place, whereas learning theories are more related to the development of literacy.

> circulation that statements become proved, facts become verified and thoughts become objects of reality. Consequently, textbooks do not merely serve to transmit an already established phenomenal world to the novice generation, but are part of the continuous process of changing the phenomenal world. (Brorson and Andersen 2001, p. 123)

To sum-up this section, several issues seem to be quite obvious. Kuhn had read Fleck's book and consciously or unconsciously was inspired by his philosophical thinking. This has already been acknowledged by Kuhn (1962). On the other hand, it was Kuhn's popularity and possibly also his personal influence (Kuhn 1979), which to a certain extent, helped Fleck's work finally receive the international recognition it deserves in the field of modern philosophy.

5 Potential Impacts and Applications of the "Genesis and Development of a Scientific Fact" for the Teaching and Learning of Science

In recent years there has been a call to include ideas related to the nature of science in the science curricula (e.g., McComas 1998).[7] This is to ensure that learners can understand and be able to participate in decisions created by new developments in science and technology. It has been suggested that these needs should also include both a sociological understanding of the scientific endeavor itself and a description of the influence and involvement of science in society (Eilks et al. 2014; McComas et al. 1998). However, many students, even those who intend to become scientists, are unaware of the accepted understanding nature of science (Irwin 1996). They may regard science as a systematic gathering of facts and theories. However, very often they are not aware of the nature of the scientific endeavor. They lack an understanding of the roles and practices of scientists and their community (Grosslight et al. 1991; Hayes and Perez 1997; Jungwirth 1987). Arons (1984) claimed that many science teachers do not devote enough time for discussing the nature of the scientific process and, as a result, miss crucial opportunities to introduce a critical understanding of the nature of science. It has been suggested that discussing Ludwik Fleck's ideas about the different issues of the nature of science might contribute to closing this knowledge gap.

Heering (1998, 2007) suggested expanding Fleck's system of *thought style* with what he calls *experimentation style*. Parallel to *thought style*, the term *experimentation style* can be defined as the directed manipulation of an intentionally designed apparatus with a corresponding mental and objective assimilation of what has been observed. However, it is important to note that although Fleck mentions experiments and even laboratory practices several times, both in his monograph as well as in several of his articles, he was mainly addressing "the experiment" and not experimental practices. As a result, Fleck did not discuss specific experimental procedures at a similarly sophisticated level as he did cognitive procedures. This is not too surprising when Fleck's work is placed in a historical context—experimentation was not considered to be problematic from an epistemological point of view in the 1920s and 1930s. It was only during the last quarter of the twentieth century that philosophers of science developed a more sophisticated understanding of experimental practices in the process of knowledge generation. Hacking's now-famous essay "Experimentation has a life of its own" (Hacking 1983, p. 150) can be seen as an indication of this change.

7 See also Erduran et al. (2007), Lederman (1992), and Mamlok-Naaman et al. (2007).

Nevertheless, Fleck can be interpreted in such a way that the collective is not just the carrier of the *thought style*, but the carrier of the experimentation style as well. In this respect, the *thought collective* defines which operations (with which the instrumental arrangement and in which environmental setting) are considered appropriate in order for them to be perceived as scientifically experimental practices. This suggests that these standards are not always stable over time, but will eventually change, as suggested by Hacking (1983). As a result, it is evident that there is not one scientific method, as was suggested by McComas et al. (1998), who stated that there is "no one way to do science (therefore, there is no universal step-by-step scientific method)" (McComas et al. 1998, p. 6). McComas and his colleagues (1998) argue not only for accepting the plurality of scientific methods dependent on the scientific discipline, but also for changes over time. This means that the method employed is dependent upon the different *thought styles* at a certain point in the history of science. It is not only the theory but also the experimentation style that results in a variety of scientific methods over time. Consequently, experimental standards are no longer given, but are man-made, and have to be viewed as the outcome of a social process of negotiation within the *thought collective*. They are thus subject to changes. This kind of message is overlooked by most science curricula.

For educational purposes, this point of view poses problems as well as presents opportunities. One legitimization of science education is the claim that students receive insights into scientific practices. If these practices are time-dependent in the manner described above, it is evident that the classical experiments are no longer considered to be appropriate in terms of the actual standards of scientific knowledge. Moreover, there are no longer *the* scientific standards, but only standards according to a *thought collective* at a certain time. As a result, to legitimize this claim one would have to adapt the standards accordingly in order to enable the students to develop insights into the changes in the various research collectives.

However, one can also view this as an opportunity. Students can be confronted with different styles of experimentation. As a result, they may begin to reflect upon what is scientific about a scientific experiment (Heering 2000). This might enable students to understand scientific knowledge production as a cultural activity by reflecting on past experiments, rather than just learning the outcome as a set of rules that cannot be questioned. This might help students to develop a different viewpoint of science, which is both more realistic than the image of science created by traditional science education and one that enables students to obtain insights into scientific practices at a different level. It is not just insight into currently accepted practices that is provided, but also an understanding of how these practices are subject to change. It also lends an opportunity to participate at various levels in the process of generating new scientific knowledge.

In alignment with Fleck's ideas, students can also be taught about the reasons for innovation and about "dead ends" in science research. This can help overcome beliefs that scientific research is always straightforward, can solve every problem, and that the pure accumulation of evidence will lead to valid knowledge (McComas 1998). "Dead ends" in scientific research are not only caused by reaching the limit of potential evidence in a field. They are sometimes reached when a discipline comes to its limit in understanding something. In this case, the *thought style* is unable to recognize new pathways and solutions. This often takes place if one *thought style* is unwilling or unable to interact with another because its views are not yet part of the *thought style* of the specific *thought collective* in question. In this case, innovation is hindered if the *thought collective* does not interact with others, because the differences in *thought styles* between the two groups may prevent a fruitful understanding.

One case might illustrate this. Recently Naaman (2013) published a commentary in *Nature Nanotechnology*. He discussed the field of molecular electronics, which has gradually emerged from theory to experimental realization. One could often hear the statement that a solution 'beyond the silicon' would result. Indeed, organic molecules did find their place in organic light-emitting diodes and also contributed to photovoltaic applications. However, the concept of using a single molecule as a 'molecular transistor' still seems elusive and no actual materialization of it has been demonstrated so far. The research reached a dead end, because any attempt to replace silicon still followed the 'silicon path'.

Most of the work has focused on trying to build 'solid-state devices' using single organic molecules. Today, research has at least acknowledged where the problems lie by adopting different views from other fields. Taking into account molecular electronic concepts has helped researchers to better understand the relevant properties of the respective molecules. This is a continuation of the long tradition of molecular spectroscopy. Advantage was also taken of concepts dealing with the quantum properties of molecules. Based on these ideas, organic molecules were considered to be important building blocks in the new field of spintronics. It has been demonstrated that a single chiral molecule at room temperature can serve as an efficient spin filter. However, these quantum properties in molecules could not be realized in solid-state devices at room temperature. Hence, other avenues needed to be explored in different types of structures. In summary, molecular electronics, based on organic molecules, may eventually be utilized in exciting and novel applications, but they will not be as simple as ideas derived merely from an understanding of silicon-based electronics alone.

There is another even more general perspective in science education inspired by the works of Ludwik Fleck. It addresses the faulty belief that science is a solitary pursuit that is independent of other areas and of society at large. This includes the notion that scientific advancements always move in a straight line when solving problems, that science can somehow find answers to all of the world's problems, and that science and its technological applications in society are one and the same thing (McComas 1998).

Fleck offers a valuable framework, which via a broadened interpretation (Bauer 2009) can be used to contribute to better understanding how information from science affects society and vice versa. Such an interpretation also provides guidance regarding what must be learned about science in order to foster the societal relevance of science education (Stuckey et al. 2013). One can understand the indirect use of information from science in societal debates, if we examine the arguments using Fleck's idea (1935/1980) in Bauer (2009). According to Fleck, pure scientific information is present only in the esoteric circle of the *thought collective*. However, debates regarding SSI at the societal level do not take place in the esoteric circle of a specific scientific discipline, but rather in other areas such as politics, economics, and the mass media. All of these fields hardly overlap any of the esoteric cores in different scientific domains. This means that students participating in science- and technology-related public debates need to understand how information moves outwards from the esoteric scientific core into the public domain.

Figure 1 illustrates an educational model of how the esoteric circle in any science domain is encircled by different media domains. It starts with Fleck's concepts of journal and handbook science, in which the scientific media further disseminate information directed at broader audiences. It is important to recognize that there is a sphere beyond the exoteric circles. In public discourse there are persons contributing to the debate who may not know about or do not agree with the current *thought style* of the respective scientific experts, e.g., persons denying the existence of evolution based on their religious beliefs.

Fleck's ideas (1935/1980) can be used to describe a gradient along which information spreads from science via the widening concentric circles into society. This gradient consists of selection, simplification, and interpretation. It is clearly driven by both the purpose of the information and the target audience for whom the information is prepared. However, it is possible that the information beyond the circle of educated amateurs is denied or is completely re-interpreted based on an incompatible *thought style*.

Teaching science using this model may help laymen understand that most science-related information with which the vast majority of society comes into contact does not directly originate from authentic science. Reading popular science magazines or newspapers does not automatically mean that the reader is exposed to original scientific information. Very often, the content matter dealt with in newspapers, TV programs, or magazine articles has not even been handled by scientists who are experts in the particular scientific area in question (Eilks et al. 2014).

In the words of Fleck, the information public discourse would consist of neither journal science nor handbook science. Thus, it is not critically analyzed and proofread by experts as are contributions published in peer-reviewed scientific journals or handbooks. For the public, scientific information is mainly presented by special interest groups, politicians, journalists, and any other societal players (Hofstein et al. 2011). Because of this, many scientific facts or theories are purposely selected and presented one-sidedly; information is left out, intentionally or unintentionally biased, or used in suggestive ways. As Hofstein et al. (2011) have suggested, the information could be interpreted as 'filtered information'. In any case, the information is transformed and is not necessarily in alignment with the scientific source of it. Each step of the transformation is carried out by various individuals. As a result, the final product is substantially different from the original, either due to reasons of comprehension or because of the purpose for which the information is intended to be used. At the same time, the status of knowledge is modified. Journal science and to some extent also *vademecum* science are still characterized by the use of proofs, thus indicating that this knowledge still appears to be in flux. During the process of transformation, this status of questionability also results in changing the appearance of the information, with descriptions looking more factual instead of procedural.

To become skillful in contributing to societal debates the learner needs to understand how such science-related information enters societal discussions. To evaluate the respective information, one needs to understand which individuals or groups processed the selection, simplification, and interpretation of the information as it was transformed from science into the public realm (Fig. 2a).

Fleck's work (1935/1980) also inspires reflection about the reverse situation. Decisions in domains beyond the exoteric circles of science, e.g., politics, ethical authorities, and economics make a huge impact on scientific research and work. Two examples of this are governments, universities, and corporations that set ethical guidelines and make financial decisions about which research projects to fund (or not). Groups of societal players transform public opinion and societal interests into a framework in which scientists have to work. Again, journalists or politicians play a major role, just as NGOs and the state of the economy do.

Figure 2b presents an idea of how this might be used for students. Classroom learning, using these models, which shows the close link between science and society, can mimic authentic societal practices regarding science-related information transfer and decision-making in society. The learners can imitate the work of individuals or professional groups (in this case not scientists). Namely, they can personally use science-related information to influence a socio-scientific controversy in which they themselves take an active part. Such

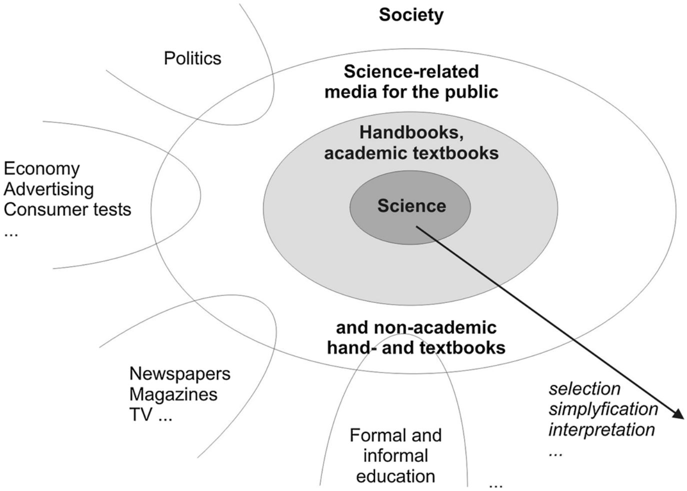

Fig. 1 A model of the science-to-society link (based on Bauer 2009)

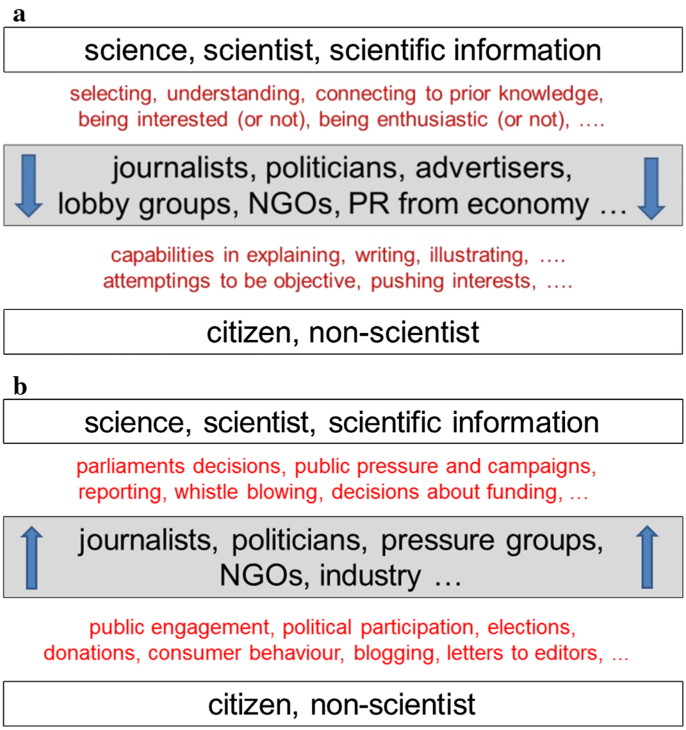

Fig. 2 **a** The double filtering process of scientific information transfer from science to society via specific societal stakeholders (Eilks et al. 2014). **b** The indirect influence of the public on science to society via specific societal stakeholders

activities include role-playing by different participants in a public debate (Marks et al. 2008), working like a journalist (Marks and Eilks 2010), researching like a consumer test agency (Burmeister and Eilks 2012), and running a business game (Feierabend and Eilks 2011) to see how politicians use scientific expertise in making their decisions.

6 Conclusions

This paper discusses the philosophical works of Ludwik Fleck. Although his ideas had already been developed during the 1920s and 1930s, they have remained largely unrecognized for many years owing to the tragic history of Ludwik Fleck's life (Leszczyńska 2009). In recent years, however, Fleck's works have been intensively discussed regarding his philosophy, due to their interrelatedness to the works of Thomas S. Kuhn (Babich 2003). However, in education, in general, and in science education, in particular, Fleck's ideas have been rarely discussed or applied.

This paper presents an overview for the science education community about Fleck's ideas. It suggests that Fleck's writings and epistemology show great potential for science education. His philosophical approach can help students achieve a much better understanding of scientific methods and also the way scientists operate and think. Additionally, this might help them understand the close links between science and its role within society. Explicitly discussing Fleck as well as working within indirectly derived educational models stemming from his ideas may help learners to better understand the nature of science. This is especially true regarding the sociological aspects of scientific endeavor. A clear understanding of the nature of science is necessary if people are to make sense of SSI and can participate in societal decision-making processes.

Further analysis may reveal even more potential and applications in adopting Fleck's theories to science education. One potential field with respect to Fleck's philosophy is that of teacher training. Maybe the ideas of the *thought collective* and *thought style* will allow us to better understand and overcome the insufficient communication and the often lacking interaction among the different groups of science education researchers, curriculum developers, and science teachers. An analysis of the similarities and differences of Fleck's epistemology in comparison to constructivist learning theory might be interesting and may reveal important insights and understandings. This has already been the case when Kuhn's work was compared to educational constructivism (Greiffenhagen and Sherman 2008).

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