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Knowledge transfer and its contexts

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HIGHLIGHTS

- The circulation of knowledge often entails a process of change and modification.
- The object transferred often needs to accommodate the commitments of the target context.
- Knowledge transfer requires the justification of the original assumptions in a novel context.

ABSTRACT

Knowledge transfer across different contexts has become an increasingly prevalent feature of current science. As such, it is a relevant topic also for historians and philosophers of science. This special issue presents a set of papers that study knowledge transfer in various disciplines. The contributions approach the topic from 1) an integrated history and philosophy of science perspective, 2) a systematic philosophical perspective, or 3) a historical perspective. Taken together, they give a broad introduction into the topic and offer a set of conceptual resources for the study of knowledge transfer in multiple contexts.

1. Introduction

Knowledge transfer has increasingly become a crucial characteristic of major research programs and, arguably, of the scientific knowledge production process more generally. Processes of knowledge transfer have mainly been studied in the history of science, sociology of science, and philosophy of science to understand what facilitates and hinders processes of circulation, dissemination, and diffusion of scientific knowledge (e.g., Howlett/Morgan 2010; Humphreys, 2002, 2004; Kaiser, 1998; Kingsland, 1995; Nersessian, 2002). Thereby, scientific knowledge has often been understood very broadly as encompassing not only abstract knowledge about scientific concepts, methodologies, models, and theories but also concrete knowledge that relates to particular kinds of disciplinary practices, such as the objects of investigation as well as their specific characteristics, technical instruments to study them, specific skills for handling those instruments, and the protocols and other procedures involved in using those instruments (see, e.g., Ash, 2006).

Exemplary cases of knowledge transfer are numerous. For instance, psychological concepts have been introduced into economic models to acknowledge various motives behind human decision-making and explain phenomena such as pro-social, habitual, or addictive behavior. The underlying idea is that such concepts could help economic theories

to better explain the effect of tax policies, trading behavior, or the exchange of goods beyond the marketplace (Falk, Fehr, & Fischbacher, 2008; Liscandra this issue; Rabin, 2002; Schmidt, 2011). Other examples are the transfer of game theoretic models into evolutionary biology or of mathematical models from physics and complexity theory into economics. The hope in the latter example, known under the label of econophysics, is to better predict the dynamics of financial markets and other economic systems by means of a different set of models than those based on standard economic assumptions (Jhun, Palacios, & Weatherall, 2017; Thébault, Bradley, & Reutlinger, 2018). Also, models from engineering, after extensive modification, have been increasingly used in synthetic biology where they have called into question a variety of basic principles of existing theoretical frameworks (e.g., Knuuttila/García-Deister this issue). With respect to cases of transferring concrete knowledge across contexts, the instrument of an experiment and the knowledge required to conduct experiments with human agents in the lab have been transferred from psychology into behavioral economics.

Such cases of knowledge transfer differ from each other not only with respect to the objects of transfer and the underlying justification for transferring them from the context in which they were developed into a specific target context; they also differ regarding kinds of contexts between which the knowledge transfer takes place. Those contexts can be particular scientific disciplines, as well as subfields or specific

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research areas—what we call *domains*. But beyond domains, contexts also include cultural, historical, political, institutional, geographical, and sociological circumstances.¹ They might be constituted by a scientific community, a network of scholars, or an organization. They might also be a set of domain-specific practices, such as theoretical frameworks, experimental procedures, or different research programs, such as fields concerned with basic research or applied research. In what follows, we will refer to all the aspects mentioned above—from scientific domains to, e.g., sociological circumstances—with the generic term ‘context’.

This diversity of relevant conceptual and phenomenological aspects in the study of knowledge transfer has led to a vast body of literature. We welcome such a composite approach to the topic and the 14 papers collected in this special issue reflect the aforementioned diversity. In presenting them, this special issue is primarily devoted to giving an overview of new research on knowledge transfer from various perspectives, to highlight open avenues for future research, and compare distinct methods with which the topic has been studied.

The history behind this special issue originates in an interdisciplinary workshop entitled ‘Knowledge Transfer and Its Contexts’ held at the Center for Advanced Studies (CAS) at Ludwig-Maximilians-University of Munich, Germany, in 2015. The main set of questions addressed at the workshop centered around kinds of knowledge transfer, the contexts in which they take place, and the way in which the objects of knowledge get modified in the process of transfer. In order to see different disciplinary perspectives and approaches, we brought together researchers from philosophy of science, history of science, and sociology of science, and from science and technology studies, as well scholars doing integrated history and philosophy of science, philosophy of science in practice, and practicing scientists. The papers provide a rich collection of examples from several research fields that historians and philosophers of science interested in the dynamics of knowledge transfer could draw upon. Altogether, their contributions to the discussion and to this special issue offer an opportunity to reflect on the topic with a breadth and scope that, to the best of our knowledge, has so far not been done.

There are at least two observations that suggest the need to study knowledge transfer in greater detail. First, knowledge transfer is what characterizes a large part of scientific research of the last decades. This is made evident by the increasing number of fields that have originated from the combination or the overlap of knowledge formerly used in distinct disciplines (see, e.g., Andersen, 2016; Larivière and Gingras, 2014). Examples of the sort that are discussed in this special issue range from synthetic biology to physical chemistry, from computational social science to genetic linguistics. Other examples include nanoscience, climate science, integrative neuroscience, and the behavioral sciences as fields that have emerged at the intersection of different disciplines. It appears evident that if we want to understand such recent scientific development, studying knowledge transfer is essential. Processes of knowledge transfer also opened up a number of questions in history and philosophy of science—which we will explore in this article—concerning the nature and the methodology of knowledge transfer, how science advances by means of knowledge transfer, the specific features of transfer processes, and their potential and limitations.²

Second, in recent decades knowledge transfer has frequently been advocated as a strategy to solve some of the most pressing issues of our

times. Addressing complex issues such as regulating an international financial system, decoding the human genome, understanding climate change, or formulating a general theory of human behavior seems to require multiple perspectives and different methodologies. The way in which solutions to such problems have been fostered has often been via a call for interdisciplinarity (Tuana, 2013).³ An interdisciplinary approach often entails the transfer of scientific theories, concepts, or techniques that were originally developed for context-specific problems. They are then applied to new problems or combined with pieces of knowledge from other contexts. As such, their application often requires re-tailoring them, adapting them to new theoretical frameworks, and conceptually and/or practically modifying them to enable this exchange. Thereby, highly specialized pieces of knowledge are removed from their original epistemic ‘habitat’ and are used as multipurpose tools in contexts they were not originally formulated for.

Related to the previous point, we notice that across the same contexts, some kinds of knowledge are transferred more easily than others. For instance, it appears that economists are more open to such transfers if the object transferred can accommodate their main methodological, ontological, and epistemological commitments (Basso, Liscandra, & Marchionni, 2017). Economists have adopted, for example, prospect theory, which has a strong conceptual resemblance with traditional expected utility theory. However, they are hesitant to collaborate with psychologists when a transfer would lead to fundamental conceptual changes such as the replacement of substantive rationality with procedural rationality (Sent, 2004). The same goes for cases such as models of financial markets from econophysics. Models from econophysics are developed by physicists and scholars working in mathematical finance, who adopt their domain-specific tools to solve problems in finance that are difficult to combine with standard economic concepts and methods (Rickle, 2008; Sinha et al., 2012). They model social interaction as equivalent to microphysical interactions of particles, and the financial market as a complex, non-linear, and dynamic system. Conversely, traditional economic models rest upon core economic concepts such as static market equilibrium and the representative agent, and assume that individual agents make choices and optimize given a set of external constraints. Such traditional models also conform with the preference of economists for simplicity over complexity of modelling procedures. These differences in methodological, epistemological, and ontological commitments may explain why economists have been less inclined to use such models than physicists, why econophysics has received more attention among statistical physicists than among economists, and why econophysics articles tend to be published in physics rather than in economics journals (Thébaud et al., 2018; Bradley/Thébaud this issue; Gingras and Schinckus, 2012).

Against the background of these observations, the aim of this overview article is to guide the reader through the collection of papers herein to identify some general, unifying features that characterize processes of knowledge transfer across contexts. In Section 2.1, we introduce the topic of knowledge transfer in its complexity by exemplifying different objects of knowledge that are transferred across contexts. In Section 2.2, we discuss what contexts are and how contexts shape and are shaped by the process of transferring knowledge. In Section 2.3, we further unpack what knowledge transfer processes amount to by looking at different levels at which such processes take

¹ Note that a domain is a context, but there are certain contexts, e.g., geographical or political contexts, that are not domains.

² See, e.g., special issues on interdisciplinarity in *Synthese* (2013), Vol. 190, and, with a particular focus on modelling, in *Studies in History and Philosophy of Science* (2014), Vol. 48. For a study of the dissemination of facts, see Howlett/Morgan (2010), and of data, see Leonelli (2016). For recent work on the philosophy of interdisciplinary sciences, see, e.g., Andersen (2016) and MacLeod (2018). Other special issues that focus on the notion of integration are Brigandt (2013) and De Grandis/Efstathiou (2016).

³ We refer to Klein (2010) for a taxonomy of definitions of interdisciplinarity in the literature and its distinction from multidisciplinary. We use the term knowledge transfer in a broader sense than interdisciplinarity, to emphasize that the exchange does not only take place across disciplines but more generally across sociological, cultural, historical, political, institutional, and geographical contexts. We maintain that integration is not necessary for successful knowledge transfer, but we also distinguish knowledge transfer from multidisciplinary, as we take it that knowledge transfer requires a genuine exchange across contexts (Grüne-Yanoff, 2016). We subscribe, however, to the non-field-level specific notions of integration as in O'Rourke et al. (2016).

place. In particular, we will focus on the following three aspects of knowledge transfer: a) the features in virtue of which objects of knowledge, such as models, theories, or scientific metaphors, can be transferred from one context to another; b) the way in which knowledge is modified—sometimes substantially—to become transferrable and rendered applicable to problems that it was originally not meant to address; and c) the role that the target context plays in determining the kind of objects that can be received in that context. Before we conclude, in Section 3 we reflect on the appropriate methods to study knowledge transfer in science.

Altogether, we take the aspects we discuss throughout the sections as characterizing different dimensions of knowledge transfer in different contexts. Analyzing them helps to address questions about the conditions under which knowledge transfers are possible and likely to occur. Our hope is that a comprehensive understanding of knowledge transfer in various contexts would ultimately allow for formulating normative standards that inform scientists and science policy alike. In this respect, our aim is to combine the description of cases where knowledge transfer takes place with an analysis of some of the aspects that scientists should consider in order to ensure that knowledge transfer is successfully done, where by success we mean that the process of transfer generates knowledge in the target context. This entails, for instance, the justification of the results of a model that has been developed in a different context and the reinterpretation of the assumptions or their modifications. Towards this goal, our analysis is meant to contribute to the line of research in history and philosophy of science that, on the one hand, makes the demands for knowledge transfer more realistic and feasible in terms of what can be achieved and, on the other hand, helps scientists to become aware of the conditions that have to be fulfilled and the kind of efforts that they will have to undertake when involved with processes of knowledge transfer.

2. Knowledge transfer across contexts

Knowledge transfer in science can generally be described as a process that presupposes at least three things: 1) it requires that there is knowledge in the source context, as opposed to, for instance, just intuitions and conjectures; it requires that 2) such knowledge gets transferred in some way from the source to the target context; and, that 3) in doing so, the knowledge transfer satisfies certain epistemic purposes, e.g., it contributes to solve a problem in the target context as a result of the transfer. In the following, we look more closely into each of these aspects by drawing upon the main contributions of the papers contained in this special issue. We will start from defining the terms of our inquiry, i.e., *knowledge* as it relates to objects of transfer and *context* as it relates to the process of transfer.

2.1. Knowledge

Generally, what counts as knowledge has been controversial in the philosophical literature. In this article, we do not engage with the epistemological debate that goes back to the definition of knowledge as justified true belief. For the purpose of this work, it suffices to say that knowledge transfer in science presupposes knowledge on at least one of the following three levels: First, knowledge that something is (true) about the world, as it results from scientific theories, methods, or concepts as representations; second, knowledge of models, scientific theories, methods, or concepts; third, knowledge of how to use a set of tools, methods, techniques, or skills and expertise—or, more generally, certain knowledge objects—in order to conduct scientific research and advance the research process. The first and the third kind of knowledge—sometimes also distinguished as knowledge-that and knowledge-how—are common in the literature (see, e.g., Fantl, 2017). Together with the second, they can be the object of knowledge transfer. They can be transferred separately or together; in the latter case, they can be combined and thereby reorganized and modified in light of emerging

constraints and opportunities. Most contributions to this special issue discuss one of these cases: a) knowledge that is offered by a particular knowledge object—a theory or model; b) knowledge of a particular knowledge object, for instance knowledge that a particular theory or model exists and what it amounts to; c) knowledge of the ways in which a knowledge object can be applied in another context; and d) knowledge as a combination of the previous three.

In his paper entitled *Project Knowledge and Its Resituation in the Design of Research Projects: Seymour Benzer's Behavioral Genetics, 1965–1974*, Robert Meunier calls such a combination of kinds of knowledge ‘project knowledge’ (Meunier, this issue). Meunier defines project knowledge as knowledge that researchers need in order to design and carry out a research project and produce new knowledge. In his paper, he introduces a framework for analyzing project knowledge and discusses how it gets transferred across different experimental settings. Meunier makes a distinction between ‘goal knowledge’, which consists in knowledge about what can be achieved in a project, and ‘implementation knowledge’, which concerns the methods applied, the representations used, and the way activities are organized to execute the project. While implementation knowledge is about how to achieve the possible goals of a project, it goes beyond procedural knowledge (or knowledge-how), which he takes to be required primarily for undertaking experimental activities in the context of the project only.

Working with a case study from experimental biology, Meunier shows that both kinds of knowledge can be recombined to create new project knowledge. This recombination requires the possibility of flexible decoupling of knowledge in the source domain and its adaptation in different target domains.⁴ Because project knowledge is normally acquired in specific local settings and for particular purposes, the possibility for desituating and recombining such knowledge is part of the conditions that enable the transfer of project knowledge. Project knowledge can furthermore be made explicit as opposed to be left tacit, for instance in the context of research articles. This enables the transfer of the project knowledge by its resituation. The notion of resituation (Morgan, 2014) offers an account of knowledge transfer that emphasizes the adaptation of the knowledge and the shaping of the target context as opposed to mere diffusion of knowledge into a new context. The resituation of project knowledge is thus an example of a kind of knowledge transfer that not only leads to changes in the knowledge transferred but also in the target domain to which it is transferred.

Knowledge can also be specified by emphasizing different kinds of knowledge objects that are being transferred. Large parts of the literature on knowledge transfer have focused on model transfer as one kind of knowledge object. Several papers in this special issue expand on this literature by looking at how scientific models are transferred across disciplines or research fields. In most papers on model transfer, Paul Humphreys' concept of a ‘template’ is taken as a starting point to study modelling practices and model transfer. Humphreys (2002, 2004, this issue) has step-wise introduced his notions of formal templates, theoretical templates, computational templates, and computational models to make sense of the tension between two opposite features of models. On the one hand, models are highly abstract and flexible tools that can be applied in different domains to address distinct problems. On the other hand, they are informed by the phenomenon they are applied to. Humphreys solves this tension by tracing a process of specification, which starts with formal templates that are turned into applicable models (see also Section 2.3.1).

As opposed to Thomas Kuhn, Humphreys emphasizes the aspect of construction in explaining how general representations can be transferred from one domain to another. Towards this purpose, in his paper *Knowledge Transfer Across Scientific Disciplines* Humphreys distinguishes the aforementioned four objects as follows. *Formal templates*, such as the

⁴ For a discussion on knowledge transfer as a combination of background models from different disciplines, see MacLeod/Nagatsu (2016).

Barabási-Albert preferential attachment template of network formation and probability theory are formal objects with only a mathematical interpretation. They are usually motivated by some scientific interpretation but that scientific interpretation is detachable from the template. Formal templates contain formal elements that have to be replaced by some lower-level *theoretical template* that is derived from construction assumptions. If the theoretical template is computationally tractable, it is called a *computational template*, while keeping as well its status of a theoretical template. Finally, an empirical mapping of the lower-level template to the target system is made, which Humphreys labels a *computational model*. Such a computational model amounts to an empirically interpreted lower-level template.

Humphreys contrasts his concept of a formal template with Kuhn's notion of symbolic generalizations. According to Kuhn, symbolic generalizations are generalization-sketches, i.e., schematic forms whose symbolic expressions vary across applications. They can be applied across different target systems within a given discipline by analogical reasoning. According to Humphreys, Kuhn's approach is overly psychological, as analogical reasoning appeals to the criteria of resemblance and similarity relations that scientists have to identify. These criteria are based on tacit knowledge and as such they are often not made explicit. By focusing on the construction process of templates, Humphreys' paper shows that tacit knowledge can be replaced by explicit knowledge, which allows for a more precise analysis of how a formal representation is applied in different domains. As we will see below, this allows us to reflect on the different phases of the process of template transfer from one context to another.

Beyond formal templates and scientific models, other objects of knowledge are scientific metaphors (Castellane/Paternotte this issue). While the transfer of models is usually motivated by the attempt to solve a problem in the target domain by means of methods from the source domain, metaphors do not necessarily solve open questions, but “suggest new directions of research and guidelines for exploring them” (Humphreys, 2004, p.2). Metaphors, by definition, connect different domains by transferring properties of one domain to another. In order to count as cases of knowledge transfer, however, scientific metaphors have to fulfill certain criteria. As Castellane/Paternotte explain in their paper *Knowledge Transfer Without Knowledge? The Case of Agentive Metaphors in Biology*, good metaphors have affinities to research programs in Lakatos' sense of the term: they are based on a hard core of theoretical assumptions (think of the metaphor that, e.g., non-human biological entities are maximizers), and/or on a set of auxiliary hypotheses (e.g., what those biological entities maximize), and they can enhance a programme's explanatory and/or predictive power (in case of agentive metaphors in biology, they prompted evolutionary game theory and research on the evolution of cooperation) by indicating possible ways of tackling a problem in the new domain.

The emphasis on templates and metaphors shows only a selection of the kind of knowledge that is transferred across scientific domains. Other papers in this special issue also tackle—directly or indirectly—the transfer of expertise, of empirical findings, of research methods and concepts, and of stylized facts (Liscandra this issue; Knuuttila/García-Deister this issue), the transfer of a set of mathematical tools and concepts (Herfeld/Doehne this issue), and the transfer of technological and scientific knowledge more generally (Lee this issue). We will further elaborate on these papers below.

2.2. Contexts

Moving now to the context of knowledge transfer, note that we use the term ‘context’ to indicate in a very general sense the circumstance in which knowledge is produced, transferred, and applied. Contexts can be understood as domains that are—to a certain extent artificially - separated by conventional principles of disciplinary organization (Humphreys this issue). Concrete examples of contexts of this kind that are discussed in this special issue are complexity science, ecology,

biology, chemistry, physics, engineering, linguistics, economics, and the social and behavioral sciences more generally. What this comes down to, however, is often the transfer of a specific theory, a model, or a particular instrument originating in one discipline or subfield – i.e., the source context—to address a problem in another discipline or subfield—i.e., the target context.

In their paper *Modelling Gene Regulation: (De)compositional and Template-based Strategies*, Knuuttila/García-Deister (this issue) discuss case studies of two different laboratories at the California Institute of Technology to study how the disciplinary backgrounds of researchers influence the way engineering insights into gene regulation are being transferred and reconfigured in actual scientific practice. In the cases examined, models and modelling practices are the primary instantiations of knowledge transfer of engineering to biology, and apart from interdisciplinary exchange, Knuuttila/García-Deister also consider them as valuable sites for exploring philosophical questions about representation and mechanistic explanation.

The case studies show that knowledge transfer is a package deal: methods, concepts, and principles are transferred from engineering to biology, but more than one strategy for modelling gene regulatory networks may emerge from this process. The comparison of two different modelling strategies, Elowitz lab's minimal modelling approach and Davidson lab's (de)compositional mechanist approach, highlights the heterogeneity of engineering approaches in biology. Furthermore, what might seem to be a transfer from engineering to biology may also involve tools, concepts, and methods from other disciplines, such as physics, computer science, or experimental developmental biology. The study of the different strategies of modelling gene regulation in the two labs expands into a critical reflection of the recent discussion of modelling within mechanistic philosophy of science. Based on their comparative case study, Knuuttila/García-Deister argue that subsuming both (de)compositional modelling strategies aiming at concrete actual explanation and abstract minimal modelling strategies aiming at theoretical exploration under the umbrella of a mechanistic framework can be called into question. This is because of the fundamental differences between these modelling strategies and the explanations they yield compared to an account of scientific explanation that traditionally tried to make sense of scientific explanation grounded in experimental practices.

Some papers in this special issue analyze knowledge transfer processes beyond science, in contexts such as the social, political, or cultural (e.g., Dais this issue; Herfeld/Doehne this issue; Lee this issue). They thereby highlight the social dimension of science in that they offer insights into the way in which transfer processes are fostered or prevented by such contexts. These papers contribute to those areas of philosophy of science and social epistemology that consider, for instance, the negative and positive effects of social relationships and values on knowledge production and the potential influence of institutional, political, cultural, and geographical contexts on the kind of knowledge that is produced (e.g., Kitcher, 2003; Longino, 1990).

The paper *The Diffusion of Scientific Innovations: A Role Typology* by Herfeld and Doehne (this issue) suggests that, in the diffusion of rational choice theories across the social and behavioral sciences, interdisciplinary research institutions, such as the RAND Corporation or the Center for Advanced Study in the Behavioral Sciences at Stanford University, fostered interdisciplinary collaboration as well as the formation and maintenance of social networks potentially conducive to the adoption of innovative pieces of knowledge and their cross-disciplinary diffusion. They did so mainly via their organizational structure and their strong interaction and feedback cultures. Such settings fostered social interaction within and across disciplines and incentivized cross-disciplinary engagement with knowledge developed in other fields. As such, while these organizations were not solely responsible for the diffusion of rational choice approaches, they were certainly necessary in preparing the grounds for the relevant interactions between scholars to take place.

As historians of science point out (e.g., [Ash, 2006](#)), contexts across which knowledge is transferred can also refer to different geographical places. To discuss the intellectual and social conditions that enabled the transfer of thermodynamics to chemistry, Photis Dais' paper *The Double Transfer of Thermodynamics: From Physics to Chemistry and from Europe to America* (this issue) analyses how one stream of thermodynamics developed by mathematically skilled chemists at the end of the 19th century was transferred from Europe to the United States. A number of American chemists trained in German chemistry laboratories expanded the acquired knowledge according to their individual interests, their talents, and the problems they envisaged. They produced new knowledge aligned with their needs and thereby helped establish chemical thermodynamics and ultimately physical chemistry in the United States.

Contexts can also be constituted by historical episodes, sometimes with an emphasis on a particular geographical region. Such contexts can refer to intra-academic but also to extra-academic areas, as shown by Clarissa Ai Ling Lee in her study of technoscientific knowledge transfer in the context of the Malaysian nuclear science programme from the 1950s onwards. In her paper *Nuclear Science and Technology in the Malaysian Context: Three Phases of Technoscientific Knowledge Transfer* (this issue), Lee closely looks at how specific scientific practices are advanced within science policy, to show how universal knowledge is adapted to local conditions while passing through distinct technoscientific and socio-political landscapes. Lee proposes a three-stage model of knowledge transfer to analyze the interaction between science and politics, showing that the choice and subsequent adaptation of technoscientific knowledge that has been transferred is not undertaken only out of sheer curiosity but is also shaped by (local) economic, institutional, and political interests and the promise of advantages, not only for science, but also for political agendas.

Lee's paper also shows that there are practical contexts outside academia, such as the political context, that uses knowledge produced by scientists for political purposes. Specific characteristics such as epistemic, social, and geopolitical inequality between source and target context—for instance between the Malaysian nuclear science and technology programme and the programme's international partners/peers—affect the process of knowledge transfer. This is why the conditions that have to be in place when transferring knowledge from science to politics might differ from those required for cross-disciplinary transfer within science. Also, the knowledge needed in the political domain might be different from that needed in science. This is because the transfer to the political context is undertaken for different reasons, it has a different effect on what happens with the knowledge transferred in the process, and it applies distinct standards for evaluating whether a transfer of knowledge is or is not successful. For instance, crossing geographical contexts might presuppose individuals who physically travel from one country to another (see, e.g., also Dais this issue). In contrast, overcoming conceptual differences between theories of different disciplinary domains might require fundamental conceptual and theoretical modifications. To capture the transfer of technoscientific knowledge and how the conditions for its success differ, it is useful to keep different contexts separate and analyze them on a case-by-case basis.

2.3. The transfer process

The previous two sections focus in particular on defining and providing examples of 1) knowledge objects as they relate to transfer and 2) different contexts of transfer. This section discusses in greater detail how knowledge is transferred, in particular the role of the specific kind of knowledge that is transferred and of the specific kind of context in influencing the transfer.

2.3.1. The source context of knowledge transfer

One of the main issues that is analyzed when talking about

knowledge transfer concerns the characteristics that knowledge in the source context needs to exhibit in order to be transferable to another domain. Several papers in this special issue analyze the properties of different objects, e.g., models, theories or metaphors, in virtue of which they are transferrable to another context. Examples are 'phenomena neutral' modelling techniques (Donhauser/Shaw this issue), which in virtue of their lack of empirical content, can be transferred across domains; or the flexibility of theoretical concepts, which allows them to refer to objects or things in different target domains, if they are at the same time specific enough to generate knowledge in those target contexts.

With respect to the source context, several papers focus on objects that are transferred in the form of mathematical structures or syntactic units. As discussed above, Humphreys' formal templates, for instance, are mathematical objects devoid of any empirical content (Humphreys this issue, p.3). Precisely because they are domain-unspecific, they can be transferred. This, according to Humphreys, is the key to their transfer: "Because the empirical content of these formal templates is entirely restricted to the mappings onto the world, the same purely formal template can be carried over wholesale from domain to domain" (Humphreys, 2004, p.6). Examples are network models that have been used to represent different systems such as journal citation or social network formation (Humphreys, 2004 p.3). "Laplace's equation, Poisson's equation, the diffusion equation" are general equation forms that count as further examples of such formal templates (Humphreys, 2004, p.4). In his paper, Humphreys takes the opportunity to expand on his account of templates and explain how general representations can be transferred from one domain to another. Towards this purpose, he specifies the aforementioned distinction between formal and theoretical templates and how their construction process differs. According to Humphreys, a theoretical template is a "general representational device" that occurs within a scientific theory (Humphreys, 2004 p.18). It is a theoretical schema whose constitutive variables allow for re-interpretation and thus for its application to a wide range of phenomena. However, as it is part of a theory, its interpretation is constrained by the intended interpretation of the theory. In contrast, formal templates only have a mathematical interpretation and can, as such, represent a variety of different systems. As mentioned before, while they require an interpretation for their application, this interpretation is fully independent of the template itself.

Thinking of formal templates as purely mathematical objects implies that they can be transferred across domains. Making the formal template applicable in a different domain entails in turn a process of adapting the template to the target domain. No knowledge of the source domain is needed according to Humphreys to apply them in the target domain. Their interpretations, by which Humphreys means their 'empirical mapping', require only subject-specific knowledge of the target domain, i.e., knowledge about the system being represented and maybe some heuristic association abilities. As such, no vocabulary translations or interdisciplinary knowledge are needed. This stands in contrast to other papers in this special issue, which argue that knowledge of the source domain is usually necessary to successfully apply the object of knowledge in the target domain (see, e.g., Bradley/Thébault this issue).⁵

Following Humphreys, two papers in this special issue, by Lena Zuchowski and by David Anzola, illustrate the role of syntactic units at the basis of model transfer in complexity science and computational social science. In her paper *Modelling and Knowledge Transfer in Complexity Science*, Zuchowski identifies two categories of modelling activities in complexity science: First, the creation of a repository of large-scale models without fixed target systems and second, the transfer

⁵ A mediating position between Humphreys and Bradley/Thébault is provided by [Knuuttila/Loettgers \(2016a\)](#), who introduce the notion of a model template that couples formal platform with a general conceptual core.

of such models to particular target systems. Cellular automata are a classic example for the first category. They describe the evolution of complex systems; they have not been developed with a particular natural phenomenon or target system in mind, but found a wide range of applications across disciplines, from physics, to ecology, to urban planning. More specifically, she distinguishes between vertical and horizontal model construction, where the former requires knowledge about a target system while the latter does not, as it is based on the modification of an existing model. Interestingly, she shows that complexity science can advance via theoretical templates with no interpreted theory, i.e., no associated target systems.

In a similar vein, Anzola's paper *Knowledge Transfer in Agent-based Computational Social Science* describes how agent-based models have contributed to the establishment of computational social science. The process in this case is very similar to the case of complexity science, as agent-based models also offer a repository of models that can be deployed in different settings. Anzola shows, however, that the field so far has not integrated with traditional social science as much as we would expect. Two main observations may explain this situation.

First, even though agent-based models have proven to be instrumental in addressing certain social scientific questions—think of Schelling's segregation model (1971) and Axelrod and Hamilton's model of cooperation (1981)—agent-based models cover only a subset of the range of issues that social scientists typically are interested in. Other problems in the social sciences are more prone to be tackled with other methodologies, to which computational social science may have little to contribute. This, however, should not be taken as a failure of transfer. As it has been argued before (see, e.g., Grüne-Yanoff, 2011), full-blown integration might be too strong a condition to evaluate the success of knowledge transfer, as different domains may preserve their own boundaries but still benefit from external inputs.

Anzola also highlights that the relative novelty and interdisciplinary nature of the field promotes distinctive dynamics of integration and fragmentation that sometimes create tension and contradiction in processes of knowledge transfer. We can expect that tensions among scientists may often emerge when novel methodologies, such as agent-based models, are introduced to address long-standing problems in an established domain. One reason is that the novel methodologies often come with a set of methodological and conceptual requirements—for instance in the case of computational and social sciences—such as that problems should be described in abstract and simplified ways. Those requirements, however, do not necessarily correspond to the criteria that characterize explanatory standards and, more generally, practices that have been established in the social sciences. To take another example, the scepticism of some social scientists towards the use of mathematical theories of social behavior, such as game theory, might originate in the fear that such theories question long-standing assumptions and methodologies previously established that favour a qualitative approach.

We can thus add to Humphreys' characterization of knowledge transfer a first qualification, which is that formal templates are particularly apt to be transferred to those domains that a) either share with the source domain a similar methodology, or that b) deal with problems that are in principle suitable to be tackled with that methodology. In other words, beyond formal templates, the possibility of model transfer depends in an important sense on a good match between fields, where by *good match* we mean either a similar methodological approach or similar research problems.

There might be further conditions that need to be in place to enable model transfer. In certain cases, formal templates may be available, but the conditions for them to be received in the target domain are absent. An example that illustrates this case is presented in Dais' paper. Dais shows that the theoretical machinery apt to introduce thermodynamics into chemistry was developed towards the end of the nineteenth century by a group of physicists and, in particular, by one of the founders of statistical mechanics, the physicist Josiah Gibbs (1839–1903). Although

it is now recognized that Gibbs' contribution was instrumental to the rise of physical chemistry, his work was mainly ignored by contemporary chemists and in some cases even met with resistance. Dais shows that among the reasons for this reaction was that the mathematics Gibbs used was too complex at the time to be handled by chemists without a strong mathematical background. By contrast, what sparked interest in thermodynamics in the chemists' community was the work of a group of chemists who managed to make the content of their theories more accessible, via easier mathematical routes. This observation connects nicely with an observation made by Herfeld/Doehne (this issue) about the conditions for the diffusion of rational choice theories. Because they were formulated in terms of mathematical logic, including set theory and topology, which was neither taught nor generally used in the social sciences at the time, rational choice theories needed to be 'translated' for the social scientists in order to be adopted by them.

This observation also allows us to reflect on the meaning of flexibility in the context of knowledge transfer. As Dais' example shows, in spite of the fact that Gibbs' thermodynamic theory (i.e., a template) could in principle be used in chemistry, it had difficulties in being acknowledged by chemists—and did not prompt a transfer. In other words, Gibbs' template was not picked up by chemists precisely because of its complicated mathematics, which acted as a barrier rather than as a vehicle of transfer. Interestingly, the kind of flexibility at work here can be illuminated by a discussion on scientific metaphors in Castellane/Paternotte (this issue). Metaphors by their very nature are flexible, in that they display a number of features of the different contexts they refer to. As Castellane and Paternotte show, however, fruitfulness does not just depend on a vague similarity between concepts. Rather, metaphors are more fruitful the more they enable and constrain the development of a field and thus guide its development. By analogy with scientific metaphors, the fruitfulness of templates can be assessed on the basis of their contribution to a research program. While Gibbs' thermodynamics theory did not qualify as a transferrable template insofar as it was not picked up for the development of physical chemistry, according to Castellane and Paternotte's criteria, agent-based models offer a positive example of knowledge transfer that contributed to the emergence of computational social science.

The paper *Transfer and Templates in Scientific Modelling* by Wybo Houkes and Sjoerd D. Zwart (this issue) aims at further elaborating on Humphreys' template account to arrive at an even more differentiated understanding of model transfer. The main goal is to address the potential danger of Humphreys' account of compromising the representational function of templates in their transfer by reducing them to mere formalisms to enable computation. The authors ask "how templates can be distinguished from models on the one hand and purely formal objects on the other" while fulfilling their dual function of representation and facilitating quantitative manipulation (Humphreys, 2004, 2). Thereby, they ask whether templates—as a knowledge entity—are a proper unit for analyzing model transfer. Studying the case of modelling technology diffusion with the Lotka-Volterra equations from theoretical biology motivates them to restructure and extend Humphreys' notion of templates and on this basis answer this question with a clear 'yes'. In particular, according to Houkes and Zwart, analyzing knowledge transfer through the notion of template allows distinctions between different forms of transfer.

2.3.2. The transfer process

A further core issue to better understand knowledge transfer, which has so far been largely neglected in the literature, is that in many cases, knowledge has to be modified - sometimes substantially - to be transferrable and rendered applicable to problems that it was originally not meant to address (e.g., Ash, 2006). Taking models that originated in statistical physics, for example, and applying them to phenomena of interest in economics thereby replacing traditional mathematical models is a non-trivial endeavor. For one, common assumptions such as

that individuals make choices are questioned in those models. Furthermore, they might require an entire reconceptualization of the economy and its core characteristics. They do not conceptually align with the traditional conceptual and theoretical framework of economics. That might be one reason for why economists are hesitant to just replace traditional mathematical models. As such, either such physical models are considerably modified or even transformed in order to become applicable or they are not applied at all.

Several papers of the special issue describe different ways in which knowledge is modified, so that it can be received in the target context. In doing so, these papers start providing a taxonomy of the processes of knowledge *transfer*, i.e., of different aspects of knowledge from the source domain that are modified to accommodate the demands of the use or an application of that knowledge in the target domain. In what follows, we focus in particular on what kinds of modifications are needed to transfer knowledge from the source to the target context.

As we will see in greater detail below, there are examples of knowledge transfer where the content of a theory from a domain, such as physics, has to be ‘prepared’ so as to be used in another domain, such as chemistry (e.g., Price this issue). We have already mentioned that in Humphreys’ picture, this is a process of adaptation in the sense that a formal template via a modification process is adapted to the target system in the target domain. This closely connects to one important and related aspect that emerges as related to the process of transfer, namely the means by which knowledge is driven from one context to another. Humphreys (this issue) for instance argues that the various steps of the transfer process can be made explicit, whereas according to Kuhn, the transfer requires implicit knowledge that cannot be spelled out in detail. Explicit knowledge allows for the construction of formal templates as representational devices (Humphreys, 2004 p.3). In this case, templates that are originally applied to a certain target system can be seen as fully independent of their empirical content; they can take on the empirical content of another domain any time. The different phases of this process constitute the transfer from one domain to another.

In their paper on the diffusion of scientific innovation, and in particular on the diffusion of rational choice theories, Catherine Herfeld and Malte Doehne (this issue) identify translation as a modification process that an innovative piece of knowledge, for instance a theory, has to undergo to apply it in a domain other than the source domain. Their analysis of how—historically—a set of innovative tools and concepts from logic, mathematics, and probability theory that became constitutive of modern rational choice theories diffused across the social and behavioral sciences reveals that in order for a transfer to occur, the scientific innovation has to be modified and sometimes even transformed. They characterize the transfer process of innovative knowledge as a four-step procedure undertaken in scientific contributions that take on different roles: the transfer process begins with an innovative contribution formulating a new idea, which is then elaborated upon and explored with respect to its epistemic potentials; the elaborated idea then undergoes a process of translation insofar as it becomes conceptually and theoretically modified to fit a pre-existing theoretical framework or for solving a domain-specific problem. The modified scientific innovation is then applied in a fourth step by a specialist in the target domain.

In their paper *Models on the Move: Migration and Imperialism*, Bradley and Thébault (this issue) introduce the notion of resanctioning as a condition of model transfer. Resanctioning refers to the justification of the assumptions in a different domain than the one where the model was originally developed. The rationale behind resanctioning is that models that are built in a certain source domain are based on assumptions and idealizations that are specific to their original target systems. For instance, well-known models in statistical physics inspired the development of models in econophysics that describe wealth distribution. In physics, the kinetic exchange of molecules in a gas at the basis of such models assumes binary dynamical interactions between molecules. But in the case of an economic theory of exchange between

economic agents, it is not clear in what sense this assumption about molecules could apply. In other words, for the same model to be used in economics, its assumptions need to be resanctioned, i.e., they need to receive justifications that are specific to the target domain to which they refer.

The authors contrast their case, which they call *model migration*, with another instance of transfer that has received considerable attention in the literature, namely *scientific imperialism* (Clarke/Walsh 2009; Dupré, 1994, 2001; Mäki, 2009; Mäki/Walsh/Fernandez Pinto 2018). *Scientific imperialism* refers to the situation where the *explanandum* is located in a different disciplinary territory than the one for which the *explanans* was originally provided. One way to justify the outcome of the exchange is that one domain is reducible to the other: if the ontological basis of the source domain is the same as the target domain, then it is legitimate to conclude that its assumptions apply to the other domain as well (Mäki, 2009). What is important to note when considering scientific imperialism in contrast to the other mechanisms identified in the papers that underlie the transfer process is that scientific imperialism is the only kind of transfer in which the transferred knowledge is not at all modified at any stage of in the transfer process. Rather, the very idea behind imperialism is that knowledge of the source context is transferred to the target context without any change or adaptation to that target context. But there are several examples in science where models are transferred even though ontological presuppositions do not apply. The analysis by Bradley/Thébault (this issue) aims at providing justifications exactly for these cases: resanctioning stands out as a strategy that relaxes the conditions for knowledge transfer by providing a new interpretation of the underlying assumptions.

In conclusion, *translation* and *resanctioning* are two crucial aspects that characterize the landscape of what can be modified of the knowledge in the source domain, and how this can be done during the transfer process. In this context, the authors highlight a number of steps that occur “in-between” the transition from the source to the target domain.

2.3.3. The target context of knowledge transfer

A third aspect of knowledge transfer concerns the role that the target context plays in determining the kind of knowledge that can be received in that context. Important aspects are, for instance, the epistemic standards that characterize a target domain, which constrain or at least delineate what knowledge can be taken from a different domain.

Two papers in particular consider the active role of the target domains in shaping the knowledge objects they receive from the outside and their particular features. They focus on the epistemic and ontological conditions that turn out to be crucial in the process of transfer. Chiara Liscandra’s paper, *The Role of Psychology in Behavioral Economics: The Case of Social Preferences* (this issue), closely analyses behavioral economics as a field that is often taken as an example of transferring knowledge from psychology to economics. By looking at what exactly has been transferred from psychology in the case of the research program on social preferences, she shows that economics took from psychology first and foremost concepts and methods that are compatible with the main epistemic standards that characterize the discipline of economics. Explanations in economics are typically praised for certain features, such as the generality of scope and mathematically tractability. These traits are not necessarily shared with explanations in psychology, which has its own field-specific criteria of validity for explanation. When interacting with psychology, economists incorporate mainly those psychological constructs that accommodate the economists’ epistemic desiderata. In other words, the epistemic standards of a discipline act as a filter for what can be imported; they latch on to those bits of another domain that nicely fit with the economists’ goals. This aspect becomes particularly evident when comparing the transfer of the same piece of knowledge to different disciplines. In this respect, Marchionni (2013) has looked at the way in which network theory was received respectively in physics, economics, and sociology.

In this paper, she shows that different domains adapted the received theory according to their own specific explanatory styles.

In his paper *The Landing Zone – Ground for Model Transfer in Chemistry* (this issue), Justin Price's goal is to show the relevance of ontological features of a target system in enabling model transfer. In a paper that complements Humphreys' template account, Price argues that model constructions require ontological commitments that have to be compatible with the target system they are applied to. Price's contribution is to explore this idea by introducing the notion of a 'landing zone', which is a model's target system specifically designed by the modeler to fulfill two functions: first, being the target for the mathematical description of a model and second, making possible the applicability of the template as a transferable piece of mathematics. Price motivates his notion of the landing zone by studying in detail the adoption of quantum chemistry to describe chemical phenomena. More specifically, he looks at the transfer of two templates from physics, e.g., the virial theorem and the wave function, to the chemistry model of quantum theory of atoms in molecules. The 'landing zone' of the topological atom as an ontologically compatible target system prepared the grounds for model transfer from physics to chemistry. In other words, Price shows that in the transfer of quantum mechanics, chemistry—the target domain—had to prepare itself to receive knowledge from the source domain. This preparation involved the *invention* of new notions in chemistry that could make the interpretation of the template from physics meaningful in the context of chemistry. Even though the mathematics from physics was already available, chemists had to actively create an ontological 'landing zone' that could accommodate the requirements of quantum mechanics. By doing so, Price introduces yet another element that allows us to consider a criterion of success of knowledge transfer, which measures fruitfulness as "the invention of target system features that make possible the transfer of mathematical tools across disciplinary lines" (p.6).

3. Methods

Against this background, it becomes clear that knowledge transfer is a complex matter in that it involves various elements—knowledge, source, and target domains, transfer conditions, transfer processes—that can change, influence each other, and occur together in different combinations. This is an impediment to a general account of knowledge transfer that applies to all cases, and supports the need for an integrated approach. This observation makes an integrated approach useful. This relates to a final reason for having a special issue on the topic. The various papers represent different approaches to the issue of knowledge transfer in science. Some authors take a more traditional approach, such as the use of case studies to inform a more systematic philosophical analysis. Others apply empirical, formal, and qualitative methods to identify common patterns and general characteristics of knowledge transfer. Examples of such methods are, for instance, simulations, scientometrics, agent-based modelling, and network analysis. They are commonly applied in social epistemology, sociology of science, and history of science and may allow for identifying specific characteristics that do not necessarily appear from single case studies but from generalizations about transfer processes.

The usefulness of combining such methods towards studying knowledge transfer in an integrated way should be further discussed. Giving a more detailed analysis is beyond the scope of this overview article. However, it should be noted that in studying knowledge transfer in various contexts, philosophy of science can learn from history and sociology of science in taking a broader understanding of what can be subsumed under the label 'knowledge'. When knowledge transfer is studied, this appears to be especially relevant for two reasons. First, when we take a very narrow understanding of knowledge, it might

become difficult to capture the process by which knowledge circulates, diffuses or is transferred from one context to another. But 'transfer' means in some cases modification or even transformation. For instance, in the case of game theory, what is used as a scientific theory in one context is then used as a tool for conceptual exploration in another context. If we appraise game theory only as a scientific theory without studying the process by which it is transferred into other contexts, we might miss out understanding its nature and its potential epistemic advantages when appraising it as a tool. We would, as such, neglect important aspects of the nature, the outcome, and the fruitfulness of this transfer process. But the point is precisely that the usefulness of a particular theory can also be assessed on the basis of its suitability to be transferred from one context to another to address particular problems in the target context.

Apart from discussing the usefulness of such methodologies and how they can be combined in a fruitful way, it is important to involve scientific practitioners in the discussion to better understand the conditions under which they consider knowledge transfers, and the processes by which knowledge is modified, to be feasible. Such an exchange between scientific practitioners and scholars studying science enables us to draw normative conclusions that can secure the fruitful transfer of knowledge. That way, we can make philosophical, sociological, and historical analysis relevant and useful for science itself.

4. Conclusions

The main aim of this article was to reflect on the conditions under which it is possible and highly probable that a certain piece of scientific knowledge that is generated in a particular (source) context gets transferred to a different (target) context. While doing so, we have directed our attention on some of the tasks that scientists will have to perform when involved with processes of knowledge transfer.

Of course, one of the first objections to the possibility of knowledge transfer is what Donhauser and Shaw in their paper (*Knowledge Transfer in Theoretical Ecology: Implications for Incommensurability, Voluntarism and Pluralism*) label Kuhn's 'incommensurability view'. On this view, knowledge transfer across incommensurable paradigms is either impossible or extremely hard to achieve. Given that there is no neutral observation language and that scientists hold different ontological perspectives, methodological standards, and epistemological values, there is no way in which scientists would engage with knowledge generated in a paradigm different from their own, let alone deciding to apply it to some problems in their own field (Donhauser/Shaw this issue, p. 3).

Against this view, Donhauser and Shaw argue that the "stronger versions of the incommensurability thesis really pose no threat to scientists' ability to collaborate and move relatively unhindered across domains" (Donhauser/Shaw this issue, p. 8). By means of a critical discussion of two case studies, in which Kuhn's criteria for the incommensurability view are fulfilled, the authors show that successful model transfer even led to "game changing advances in how [...] research was done thereafter" (Humphreys, 2004, p. 7). What Donhauser and Shaw conclude is that knowledge transfer "does not require full, and apparently not even approximate, overlap to be successful" (Donhauser/Shaw this issue, p. 8). The only requirements for successful transfer are that modelling techniques are in the first instance what they call "phenomena neutral"; they are "neutral inferential tools" (Donhauser/Shaw this issue, p. 8). This concept reminds us of Humphreys' notion of formal templates as mathematical objects devoid of any empirical content. Recall that, according to Humphreys, knowledge of one domain is not required for its interpretation and application in another domain.

Neutral modelling techniques and formal templates suggest one way of circumventing the incommensurability thesis and the obstacles that

Kuhnian paradigms pose to knowledge transfer. Surely, when the same ontological, methodological, and epistemological commitments hold across contexts, it is plausible to conclude that knowledge can be directly transferred from one context to another without the need of particular modifications. Here, knowledge of, e.g., a model can be directly transferred to another context, insofar as that piece of knowledge promises to offer a solution to a problem in the other context. But this kind of knowledge transfer is a limiting case, given that it rarely happens that the same commitments hold across contexts. Most of the times, the assumptions that are considered to be legitimate in a certain context are different from the assumptions that are considered to be legitimate in another context. Humphreys suggests that, in these cases, we can undertake knowledge transfer by completing a process that can be broadly reconstructed as follows: we start with a purely formal template that only counts as a syntactic unit without any interpretation; and then, we move that template to a domain that invests it with an interpretation and a set of assumptions that belong to that new domain and its phenomena. In this way, we have a justification for the transfer even in those cases where the disciplinary commitments differ across contexts.

Interestingly, a similar story applies to a very different case, namely that of scientific metaphors: they are objects that can be transferred from one context to another in virtue of their flexibility. And by flexibility it is meant, among other things, that the metaphors need to be general enough so that their conceptual assumptions are not in conflict with those of the contexts into which they are transferred.

If we move to the specific features of the process of transfer, there are certain specific steps that often need to be taken when transferring knowledge from the source context to a new context. Scientists might need to translate certain aspects of knowledge so that it can be adopted and then applied in another context. Or, they may need to find a way to justify those aspects—for instance, a set of assumptions—in the new context. And finally, we considered the way in which the target context determines how a certain piece of knowledge can count as knowledge in that context. In particular, we discussed the active role of the target context in filtering out those aspects of knowledge that accommodate the epistemic standard of the context or in introducing new features that allow the assumptions of the initial context to apply to their context.

The papers of this special issue discuss several accounts of knowledge transfer already existing in the literature (e.g., Howlett/Morgan 2010; Leonelli, 2016; Humphreys, 2002, 2004). Most of those accounts focus on a particular kind of knowledge, such as facts, data, or models. While those accounts are highly important for the topic, our focus in this overview article has been on transfer of knowledge broadly conceived. Related to this, the article draws on a large set of examples from different areas of science. This clearly makes it difficult to accommodate all the specific features that characterize each case. Still, our main effort has been to extract a number of general properties that emerge from their analysis. Given the diversity of the examples, it is even more surprising to observe many common features characterizing the process of knowledge transfer across them. We hope that, by systematizing some of the most recent work on the topic, our analysis will foster the current debate and indicate possible developments for future research.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.shpsa.2019.06.002>.

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