Specialisation, Interdisciplinarity, and Incommensurability

Vincenzo Politi

Instituto de Investigaciones Filosóficas, Universidad Nacional Autónoma de México

ABSTRACT Incommensurability may be regarded as driving specialisation, on the one hand, and as posing some problems to interdisciplinarity, on the other hand. It may be argued, however, that incommensurability plays no role in either specialisation or interdisciplinarity. Scientific specialties could be defined as simply 'different' (that is, about different things), rather than 'incommensurable' (that is, competing for the explanation of the same phenomena). Interdisciplinarity could be viewed as the co- ordinated effort of scientists possessing complementary and interlocking skills, and not as the overcoming of some sort of incommensurable divide. This article provides a comprehensive evaluative examination of the relations between specialisation, interdisciplinarity, and incommensurability. Its aim is to defend the relevance of incommensurability to both specialisation and interdisciplinarity. At the same time, it aims at correcting the tendency, common among many philosophers, to regard incommensurability in a restrictive manner—such as, for example, as an almost purely semantic issue.

1. Introduction

Scientific change is an issue that, in philosophy of science, is often discussed from an intra-disciplinary perspective—by analysing, for example, changes within physics, within biology, and so on. In this way, the debate on scientific change risks being reduced to the study of how different theories follow one another within disciplines, the boundaries of which are considered to remain relatively fixed in time.

Scientific disciplines, however, are themselves historical entities (Toulmin 1962; Lenoir 1997; Suárez-Diáz 2009): they may grow, evolve, change, and even lead to the creation of new disciplines. This is why it is important to look at scientific change from a more interdisciplinary perspective, by considering, for example, those cases when a scientific discipline splits from one or more pre-existing disciplines, as in the process of specialisation, or when two or more disciplines merge, as in interdisciplinarity.

One of the few philosophers who discusses specialisation within a theory of scientific change is Kuhn (2000), who believes that the phenomenon of the proliferation of special- ties is driven by incommensurability. However, it may be argued that scientific specialties are not ‘incommensurable’ (that is, holding conflicting views about the same range of phenomena), but simply ‘different’ (that is, about different ranges of phenomena). Moreover, it is not clear how interdisciplinarity would even be possible if it were true that differ- ent specialties were separated by incommensurability.

This article provides a comprehensive evaluative examination of the relations between specialisation, interdisciplinarity, and incommensurability. Its aim is to explain the relevance of incommensurability to specialisation and interdisciplinarity. At the same time, it aims at correcting the tendency, common among many philosophers, to regard incommensurability in a restrictive manner—such as, for example, as an almost purely semantic issue, having to do with meaning variation and communication problems.

In Section 2, Kuhn’s incommensurability thesis is briefly discussed. In Section 3, we explain that, in order to understand the role of incommensurability in scientific specialisation, the latter must be regarded as a complex historical process. In Section 4, we explain how it is possible that different specialties may become incommensurable through interdisciplinarity. In Section 5, we discuss how incommensurability can shed some light on the actual practice of interdisciplinary research. We conclude, in Section 6, with some further reflections on incommensurability and scientific change.

2. Kuhn’s Incommensurability Thesis

In mathematics, the concept of incommensurability refers to a two-way relation between magnitudes lacking a common measure for their comparison. For example, the radius and the circumference of a circle are incommensurable, since their ratio cannot be expressed by an integer number but, instead, by the irrational number π.

The incommensurability thesis, introduced by Kuhn ([1962] 1996) and Feyerabend (1962), is a philosophical thesis about scientific knowledge. Kuhn and Feyerabend used the term ‘incommensurability’ metaphorically, to describe the lack of a common measure for the objective comparison of two competing paradigms, or theories, or scientific traditions. Since this article is concerned with the role of incommensurability in specialisation and interdisciplinarity, and since Kuhn developed a model of specialisation as driven by incommensurability, we will focus on Kuhn’s version(s) of the incommensurability thesis.

In The Structure of Scientific Revolutions (Kuhn [1962] 1996), incommensurability describes the lack of a super-paradigmatic way to evaluate conflicting paradigms during a revolution. ‘Paradigm’ being a notoriously polysemous term (Masterman 1970), the ‘lack of a common measure between conflicting paradigms’ may mean many things. In its early formulation, indeed, Kuhn’s incommensurability thesis refers to: the lack of a shared theoretical vocabulary; the lack of shared methodologies for choosing and solving scientific problems, as well as for assessing their solutions; the lack of a common way of looking at the world and perceiving similarities/dissimilarities relations among problem situations.

Despite the richness of the early formulation of incommensurability, philosophers focused mainly on its semantic aspects.

On the one hand, many philosophers felt compelled to criticise the so-called contextual theory of meaning, on which the semantic aspects of incommensurability rely. Such a theory states that the meaning of a word is determined by its theoretical context. It follows that the same word, if used within different linguistic frameworks, may acquire different meanings. This would explain why scientists belonging to different scientific traditions appear to talk at cross-purposes and may experience occasional communication breakdowns. Putnam (1975) and Kripke (1980) developed theories of meaning based on reference stability as a response to semantic incommensurability. Kuhn (1990, 2000), however, attacked Putnam's and Kripke's views: while 'rigid designation' can guarantee reference stability, he argued, it is not enough to also guarantee meaning stability and avoid incommensurability.

On the other hand, after the publication of Structure, Shapere (1966) argued that the idea of meaning variation implying incommunicability across paradigms is contradicted by Kuhn's own historical work, in which past theories are translated in a present-day language. In reply, Kuhn (2000) explained that incommensurability is always local, in the sense that it involves only a restricted cluster of inter-defined scientific terms. The remaining parts of the scientific (and the common) language guarantee cross-paradigmatic communication.

To strengthen the idea of the 'locality' of incommensurability, Kuhn began to focus more on the analysis of the linguistic/conceptual elements of scientific theories and developed a 'taxonomic' version of incommensurability. In his mature view, the conceptual structure of a scientific theory is constituted by 'kind terms', which are 'taxonomic' in the sense that they can be systematised in a taxonomic fashion. Being taxonomic, the conceptual structure of a scientific theory must respect the so-called no-overlap principle, which forbids that an entity can be classified as being part of two different kinds (Hacking 1993).

For example, Ptolemy's and Copernicus's cosmologies are taxonomically incommensurable, because there cannot exist a conceptual taxonomy in which the moon is both a planet (as in the Ptolemaic classification) and a satellite (as in Copernicus's): such a taxonomy would clearly violate the no-overlap principle.

Leaving aside the assessment of its merits, it looks like, at the heart of the local/taxonomic incommensurability, there is a strong semantic flavour, also due to Kuhn's insistence that incommensurability leads to 'translation failures' between clusters of interdefined kind terms (Sankey 1998).

The trend of examining the semantic aspects of incommensurability seems to persist, due in part to Kuhn's own late focus on the linguistic features of scientific theories, which some philosophers interpret as the result of a sort of 'linguistic turn' (Irzik and Grünberg 1998; Bird 2002; Gattei 2008).

For example, Sankey (1994) begins his monograph devoted to the incommensurability thesis by saying that incommensurability 'has to do with the nature of the semantic relations between the languages employed by scientific theories' (Sankey 1994, 1). In so doing, he seems to assume that the only version of the incommensurability thesis is the semantic one, and that the only problems incommensurability poses are about inter-theoretical translatability.

Furthermore, Kuhn's contextual theory of meaning is still hotly debated. Bird (2000, 2002) argues that such a theory inherits the same problems of the theories of meaning developed by the empiricist tradition—that is, by that philosophical tradition that Kuhn aimed to demolish and surpass. Read and Sharrock (2002; Sharrock and Read 2002) dis- entangle Putnam's and Kripke's theories of reference stability, arguing that Kuhn's arguments were against the former but not the latter. They also offer a defence of Kuhn's theory of meaning, although Bird (2004a, 2004b) develops some counterarguments. Kuukkanen (2008, 2010) provides an extensive and detailed study of the issue of meaning change in Kuhn's philosophy and shows, contra Bird, how Kuhn's late theory of meaning, instead of being a disguised version of a rather passé empiricist theory, can have some relevance in current analytic philosophy.

This tendency focuses almost exclusively on theories of meanings and translation problems, and risks reducing the whole of incommensurability to communication failures. However, not only, as we explained, did Kuhn argue that incommensurability does not imply incommunicability but, furthermore, communicability does not imply the absence of incommensurability.

Methodological incommensurability, for example, poses a problem to scientific practice but it has hardly to do with communication failures. As Kuhn (1977) explains, in order to be accepted as 'scientific', a theory must possess a set of values, namely accuracy, consistency, breadth of scope, simplicity and fruitfulness. Such values represent 'minimal standards' of scientificity and different groups of scientists may 'weight' them differently. For example, a group of scientists may prefer the theory that is more accurate and consistent, while another group of scientists may prefer the theory that carries the promise of being more fruitful. The fundamental disagreement over scientific standards has little or nothing to do with problems of translation or with the meaning of scientific terms: two groups may continue to disagree even when they fully communicate and understand each other, without experiencing any 'communication breakdown'.

The long debates about Kuhn's theory of meaning notwithstanding, it looks as though the interest for the methodological aspects of incommensurability is regaining momentum among philosophers. It has been recently argued, for instance, that some episodes of revolutionary scientific change can be better understood as being characterised by methodological rather than by semantic incommensurability (Chang 2012). Okasha (2011), who has re-read Kuhn's view on methodological incommensurability through the lenses of social choice theory, has also generated a considerable debate—see Bradley (2017), Morreau (2015), Okasha (2015), and Stegenga (2015).

Finally, the cognitive/perceptual aspects of the early formulation of the incommensurability thesis have been expanded upon by Margolis (1993) and, more recently, Bird (2005, 2007). Kuhn, it should be recalled, was inspired by the experiments on perception and recognition conducted by Bruner and Postman (1949). Inspired by these empirical studies, he conjectured that scientists from different paradigms see the world differently. For example, when looking at a pendulum, an Aristotelian sees a grave striving to get back to its natural place, whereas a Newtonian sees a problem to be solved by applying the laws of motion of classical mechanics. In this sense, incommensurability is a thesis about how scientists belonging to incommensurable paradigms see the world (of scientific research) in irreconcilable ways. This is why, for philosophers like Bird, incommensurability should be understood with the aid of empirical disciplines, such as experimental psychology and the cognitive sciences. In his view, there is more to incommensurability than Kuhn's theory of meaning.

Some philosophers have recently recovered Kuhn's early analysis of the scientific problem-solving practice, and defended the value of a broader notion of incommensurability thesis accordingly (Richardson 2002; Rouse 2003, 2013). In this article, we agree with those philosophers who claim that incommensurability should not be discussed only in relation to theories of meaning and as causing just problems of communication. In fact, we apply a broadened view of incommensurability to our understanding of the processes of specialisation and interdisciplinarity. Although Kuhn developed his view of incommensurability across specialties in his late writings, we suggest that what plays a role in both specialisation and interdisciplinarity is something similar to what was described by Kuhn's early formulation of the incommensurability thesis. Rather than focusing on translation problems and theories of meaning, that is, we will consider incommensurability as a complex issue involving semantic, methodological, and cognitive/perceptual elements.

3. Disciplinary Differentiation and the Dynamics of Specialisation

That contemporary science is characterised by specialisation is a hardly controversial matter of fact. Rescher, for example, notices that while specialties in physics numbered 19 in 1911, in 1954 they were 100 and, by 1970, they were more than 200 (Rescher 1978, 229). It is not just that there are more specialties and sub-disciplines now than in the past but, also, that their number keeps growing.

Towards the end of his career, Kuhn (2000) became increasingly interested in the process of specialisation, which, in his view, is driven by incommensurability. Having already abandoned the concept of a paradigm in favour of the analysis of the linguistic aspects of science, he describes the incommensurability driving specialisation as a conceptual/linguistic barrier that makes cross-disciplinary communication difficult. He explains that ‘by barring full communication with those outside the group, [incommensurability] maintains their isolation from practitioners of other specialties’ (Kuhn 2000, 98). In this sense, incommensurability acts as a segregating mechanism that enables the establishment of new specialties by isolating them from the pre-existing ones.

One of the problems with the Kuhnian model of specialisation is that it is not entirely clear in which sense different specialties should also be considered as incommensurable. For example, Andersen argues that

> the conceptual disparity between two different specialties ... is very different from the conceptual disparity between the two specialties at each side of a revolutionary divide. Specialties at each side of a revolutionary divide address in some way the same domain and compete on offering the better account of their common domain. This is a relation of incommensurability that may imply severe communication difficulties based on, for example, disagreement on which entities exist in the world. On the contrary, although different disciplines may address domains that are in some ways partially related, they usually do not compete on offering the better—and in the end the only—account.... Hence, focussing on communication between different disciplines it is important to bear in mind that in case there is no or little communication between different specialties, this does not necessarily reflect incommensurability but may simply reflect the fact that these specialties address issues that are in some way or other unrelated. (Andersen 2012, 273–274)

Andersen develops this argument in several papers (Andersen 2012, 2013a, 2013b, 2016). In her view, the supporters of different paradigms during a revolution may experience the occasional communication breakdowns associated with incommensurability because they hold and defend incompatible and competing views about the same range of problems and phenomena. Scientists from different specialties, by contrast, do not find themselves in such a state of competition: their research is just about different things. It is not like scientists from different specialties cannot communicate in principle; they just do not communicate.

One could reply that different specialties are incommensurable simply in virtue of their being different. Such a reply, however, would trivialise the whole concept of incommensurability. Intuitively, the idea of incommensurability contains more than mere difference. Theories, methods, and paradigms that are about different things may peacefully and unproblematically coexist within the ‘Republic of the Sciences’. The incommensurability thesis, however, acquires its philosophical relevance in the context of the assessment of competing and conflicting views about the same problems—for instance, when an exclusive choice between two incompatible paradigms is demanded. Therefore, if one claims that specialties are incommensurable, one should also be able to clarify in which sense they are not just different.

However, if specialties were really incommensurable, and not just about different things, then it would mean that their domains should at least partially overlap. The problem is that specialisation does not seem to lead to the creation of overlapping domains too often. In fact, the process of specialisation seems to be a process of differentiation. Such a process leads to ontological fragmentation, with each newly created discipline being focused on its own narrow domain. This aspect of specialisation becomes more evident when considering one of the examples provided by Wray (2011).

In his recent interpretation of Kuhn, Wray (2011) takes the creation of virology as an example of the Kuhnian model of specialisation. Virology was established as an independent discipline after some bacteriologists discovered viruses. It turned out that viruses were not a sub-kind of bacteria, but a new kind of entities altogether. The new entity called virus could not simply be added as a branch of the pre-existing taxonomy of bacteriology. The discovery of the new kind leads to the split of virologists from the community of bacteriologists and to the establishment of virology as a separate specialty (Wray 2011, 129–133).

For Wray, the classification systems of viruses and bacteria were 'taxonomically incommensurable' in the sense briefly explained in section 2: there can be no *lingua franca* in which some entities can be classified as being both a virus and a bacterium. Contra Wray (and Kuhn), however, the relation between virology and bacteriology seems to be of difference, rather than of incommensurability. The ontological domain of virology does not overlap with the ontological domain of bacteriology and the two disciplines are not competing for the explanation of the same range of phenomena. In other words: while, for example, the Ptolemaic and Copernican classifications provide conflict- ing classifications of the same entities, the celestial bodies, and are therefore incommensurable, bacteriology and virology classify different entities.

To understand why it is legitimate to consider incommensurability within a model of specialisation, we suggest, it is important to remember that Kuhn's philosophy looks at science from a historical perspective, not as a static body of knowledge. Philosophers like Andersen seem to develop their considerations against the idea of incommensurability across specialties by looking at how different specialties are now. In this way, they take a 'presentist' approach to the current structure of the tree of scientific knowledge. By doing so, they dismiss the very dynamics of specialisation. What we are suggesting here, by contrast, is to look at how scientific specialties came to be differentiated.

To illustrate this point, we briefly revisit the example of the creation of virology. As Wray points out, the creation of virology was driven by the discovery of a new kind, the virus. Such a discovery possesses the same complex historical structure described by Kuhn (1962). To begin with, it is not entirely clear when or by whom viruses were actually discovered. Although the term ‘virus’ was used, in a very loose sense, in the context of the medical sciences of the nineteenth century, for a long time it was believed that viruses were special types of bacteria. That viruses could be different from bacteria was first claimed by Martinus Beijerinck, a scientist researching the causes of the so-called mosaic disease affecting plants and flowers. This rather common plant disease had been studied for cen- turies, but its pathogen agents were isolated only in 1895 by Beijerinck, who maintained that the cause of the infection was not bacteriological.

Beijerinck’s claims generated priority disputes. On the one hand, Adolph Mayer’s earlier works on infected tobacco leafs influenced Beijerinck’s research, to the point that it may be possible to regard Mayer as the first scientist who observed the new entity. On the other hand, a few years after Beijerinck’s publication, the Russian bacteriologist Dmitrii Ivanovsky claimed that he had already discovered the viruses independently.

More importantly, the establishment of the concept of virus as a separate kind of entity was met with resistance, if not controversies. Not every scientist was persuaded that Beijerinck, Ivanovsky or others had discovered a new natural kind. Quite the opposite: for a long time, the scientific community of bacteriologists tended to regard virus as a sub-kind of bacteria. It must be added that the group of virological theorists, in turn, was split between those, like Beijerinck, who believed viruses were liquid entities, and those who thought they had a different structure; and, furthermore, between those who thought viruses belonged to the living realm and those who regarded them as non-living. Even now that virology is an established discipline, disputes about the classification of viruses persist, to the point that some argue that the idea of a monistic virological taxonomy should be given up in favour of a pluralistic classification (Morgan 2016).

Some historians read the history of the conceptualisation of virus and the establishment of virology as an instance of ‘Kuhnian revolutions’ (van Helvoort 1991, 1992, 1993, 1994). Whether one regards the creation of a new specialty as an instance of scientific revolutions or not, it remains the point that the specialisation/differentiation process is achieved through incommensurability.

During the emergence of virology, but before its establishment as a fully formed and independent field of investigation, ‘bacteriological’ and ‘virological’ theories of virus were in a state of competition for the explanation of the same range of phenomena and entities—namely, for the explanation of the causes of some diseases. Virology, in other words, was established through the development of a conception of the causes of the transmission of some disease that was in conflict with the bacteriological theories. That now virology and bacteriology are different disciplines, with their own separate domain, is beside the point: incommensurability, in fact, should be understood as playing a role during the process of specialisation, not after specialisation has been accomplished.

Unfortunately, Kuhn himself contributed to confuse this point. In some of his late writings, he speaks about scientific revolutions and specialisation in terms of, respectively, *diachronic* and *synchronic changes*. Scientific revolutions, for Kuhn, are changes of the first kind, because they involve paradigms in temporal succession. Specialisation is a change of the second kind, because different specialties do coexist at the same time. Kuhn's distinction between diachronic and synchronic changes, however, does not make too much sense: 'changes', by definition, are processes unfolding in time. Although, from the historians' perspective, a scientific revolution looks like a succession of paradigms and the tree of science like the collection of coexisting specialties, the scientists involved in both kinds of scientific change participate in a process. With this in mind, it is easy to see how the controversy between, for example, the phlogiston and the oxygen theory during the so-called chemical revolution and that between the bacteriologist and virologist theorists are similar: both controversies were generated by the conflict of incommensurable conceptual systems and, at the end of the process, one conceptual system was discarded by the other.

Granted that incommensurability plays a crucial role in the process of specialisation/ differentiation, it remains to understand whether it also plays any role in interdisciplinary research.

Kuhn's view on incommensurability as a conceptual/linguistic barrier hampering cross-specialty communication seems to be contradicted de facto by the existence of interdisciplinarity. Scientists involved in interdisciplinary research often achieve theoretical and methodological integration, which would not be achievable without cross-disciplinary interactions. Also, such a view conflicts with Kuhn's own argument, for which incommensurability does not imply incommunicability.

These problems could be solved by considering the earlier and broader version of incommensurability. In this section, we have re-discussed Wray's example of the creation of virology with the aim of showing when incommensurability plays a role in the process of specialisation. Such an example, being about a new specialty created after the discovery a new kind, is consistent with a semantic/taxonomic conception of incommensurability, which Wray actually endorses. However, it could be argued that not every specialty is created after the discovery of a new kind of entity. Sometimes, new specialties can be created by applying new problem-solving methods to old problems. In those cases, what keeps scientific specialties separated may be not the impossibility of communication, but methodological and perceptual disparities—for further details on this argument, see Politi (2018).

The problem, however, is not to understand whether incommensurability is an obstacle to cross-specialty communication but, rather, whether there is any incommensurability across specialties after that the process of specialisation/differentiation has been accomplished. This is why the next two sections will examine the issue of incommensurability in interdisciplinarity.

4. Disciplinary Convergence and the Dynamics of Interdisciplinarity

The philosophical literature on interdisciplinarity is quickly and steadily growing. Mäki (2016) has recently produced a programmatic 'manifesto' for the philosophy of interdisciplinarity, spelling out many of the desiderata that such a branch of philosophy ought to satisfy. Among other things, Mäki hopes that:

> Issues of incommensurability will make a comeback, whether semantic, methodological or some other variety, responding to the recurrent complaint that the desired communication between disciplines is difficult to generate and sustain. Different disciplines often use the same terminologies in different meanings, and they may apply different styles and strategies in posing research questions and looking for answer to them as well as in assessing the credentials of the answers given. (Mäki 2016, 338)

So far, however, philosophers do not seem to have considered incommensurability— whether semantic, methodological or of other kind—as particularly interesting in the context of interdisciplinarity.

Some of them have even suggested that incommensurability does not pose any interesting problem to interdisciplinarity, since there is not an incommensurable divide separating different disciplines to begin with. As mentioned in the previous section, this is what philosophers like Andersen argue.

When taking into account the dynamics of specialisation, it is possible to understand how disciplinary diversification is achieved through incommensurability. However, even assuming that incommensurability plays a formative role during the establishment of new specialties, there is little or no reason to presuppose that some sort of incommensurability would persist even after the diversification process has been completed. While Andersen may be a bit too hasty when she dismisses in toto the idea of incommensurability across specialties, she surely is right when she highlights that, no matter how or when they have been differentiated, disciplines which are now different are not in a state of competition and, therefore, they are not incommensurable.

Since, in her view, scientific specialties are different and not incommensurable, incommensurability plays no role in interdisciplinarity. Instead of being considered as divided by some sort of incommensurable barrier which would make interdisciplinarity difficult, the disciplines involved in interdisciplinary collaborations are to be thought as complementary and the scientists coming from different specialties as possessing interlocking skills.

This conception is further developed by Andersen and Wagenknecht (2013), who apply the intra-disciplinary model of epistemic dependence of Hardwig (1985, 1991), based on the idea of the joint integration of what different agents know, to interdisciplinary cooperation.

To explain how joint integration works in interdisciplinary research, Andersen and Wagenknecht use the example, first used by Darden and Maull (1977), of the cooperation between scientists from different biological sub-specialties. In this example, a cytologist's knowledge that 'the darkly staining bodies within the nuclei of cells which are called chromosomes are the likely location of the hereditary material in germ cells', and a geneticist's knowledge that 'there are patterns of inheritance and ... there is an entity called a gene that is causally responsible for these patterns', get somehow integrated by a third scientist, who is able to conclude that 'the chromosomes are the physical location of the genes' (Andersen and Wagenknecht 2013, 1886).

In Andersen and Wagenknecht's account, cognitive integration seems to be reduced to the synthesis of different conceptual/theoretical elements. In their example, interdisciplinary integration involves propositions belonging to the theories of cytology and genetics, and the very idea of 'integration' seems to be akin to the sum of these different theoretical parts.

This account seems to be built on Andersen's assumption that the disciplines involved in interdisciplinarity are not incommensurable, but different and complementary. The risk of such an assumption is that ease of integration could somehow be taken for granted, or reduced to an operation as simple as a sum of smaller pieces of knowledge.

In the same way in which incommensurability should not be uncritically presupposed, however, the idea that different disciplines are 'complementary' and that scientists' exper- tise is indeed 'interlocking' should not be taken for granted a priori. Whether scientists coming from different specialties have skills and knowledge which can be (more or less easily) integrated for the resolution of a complex problem can be determined only within the actual context of interdisciplinary problem-solving practice and, often, only after their interdisciplinary collaboration has revealed to be fruitful. It would be more correct to say that scientists involved in interdisciplinary research have to learn how to make their skills and expertise interlocking. This is a process which, as we will see in the next section, may involve the breaking of cognitive and methodological barriers, of the same order of those described by Kuhn's (early formulation of the) incommensurability thesis.

We suggest, once again, to look at interdisciplinarity from a dynamical/historical perspective. In virtue of their historical trajectories, different disciplines may become incommensurable when they end up converging to an overlapping area. After all, the whole idea of interdisciplinarity is founded on the belief that different disciplines may have something to say about a common range of problems.

Once they have become 'about the same range of phenomena', the different disciplines involved in interdisciplinary research may enter in a conflict, for example, about the methods for solving a complex problem. This is because, even when different disciplines converge towards the same range of problems, each discipline will have its way of conceptualising and modelling such problems. As pointed out by Alvargonzález (2011), scientific disciplines are 'operationally closed' around theories, principles, and material objects (i.e. experimental devices). In virtue of their operational closure, the success of the bonding process of two or more disciplines via interdisciplinarity cannot be anticipated in any way. In short, interdisciplinarity is not achieved by fiat. Rather, it is the result of a process in which, as will be explained in the next section, scientists may experience those kinds of cognitive barriers and fundamental disagreements that may go under the label of 'incommensurability'.

5. Incommensurability and Models of Interdisciplinarity

As argued in the previous section, in interdisciplinary research, different disciplines converge towards the same area; it is at this point that they could end up being incommensurable. However, we have not shown yet whether that is exactly the case, nor have we shown that, in case there is any, incommensurability actually poses any interesting problems to interdisciplinarity.

Even without excluding a priori the existence of some incommensurability across the specialties involved in interdisciplinarity, the very existence of interdisciplinary research shows that barriers across disciplines can be and are eventually overcome. A philosopher like Andersen, then, could accommodate her views and accept the existence of an 'innocuous' incommensurability across disciplines. She may say, for example, that since scientists divide up tasks and authority with others, incommensurability issues (which might otherwise be there) are somehow sidestepped by keeping engagement to a minimum. This would also be consistent with Kuhn's view that incommensurability does not impede communicability.

If it is residual, minimal and non-threatening, then incommensurability does not seem to pose any interesting problem to interdisciplinary collaboration and, therefore, can be treated as a non-necessary obstacle for understanding of interdisciplinarity. The advantages of not delving too much into incommensurability when talking about interdisciplinarity would be of economical order. The cost of dismissing incommensurability in the context of interdisciplinarity, however, may be an overly simplistic view of the latter.

Following Holbrook (2013), the most popular view of interdisciplinarity seems to take for granted that the end result of interdisciplinary collaborations is a sort of consensus among the different parties involved, achieved through integration. Such a view of interdisciplinarity is based on what Holbrook calls the *Habermas-Klein thesis*, from the philosopher Jürgen Habermas and Julie Thompson Klein, whose pioneering work opened up the whole field of interdisciplinary studies—see, for example, Klein (1990, 1996). The Habermas-Klein thesis states that interdisciplinary communication 'involves the integration of two or more disciplinary languages with the aim of generating a common understanding' (Holbrook 2013, 1869). In this view, interdisciplinarity is—or, at least, aims at—integration.

The limit of this model is that it fails to recognise some fundamental (theoretical and methodological) differences among disciplines and the obstacles they may pose to interdisciplinarity. For Holbrook,

> the problem is that theorists of [interdisciplinarity] who want to emphasize difference— including Klein herself—currently have no language that does not also appeal to consensus in which to make their case. If interdisciplinary communication is only about reaching con- sensus, then [interdisciplinarity] itself can be nothing other than integration—that is, achiev- ing sameness. (Holbrook 2013, 1871)

To Holbrook's observations, we would also like to add that, as recently argued by several philosophers, integration is not necessary to interdisciplinarity. It has been observed, for instance, that there can be successful instances of interdisciplinary interactions without integration (Grüne-Yanoff 2016). The scientific practice taking place at the frontiers of different disciplines may lead to the creation of 'model-templates' (Knuuttila and Loettgers 2016), 'repertoires' (Ankeny and Leonelli 2016) or 'migrating models' (Bradley and Thébault 2017), which are used by more than one discipline at the same time but without the aim of integrating them. In short, not all the research labelled as 'interdisciplinary' aims at integration, but the Habermas-Klein thesis fails to capture these instances of interdisciplinarity.

Holbrook suggests two alternative models of interdisciplinarity, based on, respectively: the *Kuhn-MacIntyre thesis*, which holds that 'different disciplines are in principle and often in fact incommensurable, and so [interdisciplinary] communication can only happen if one first learns the language of another discipline from within as a second- first language' (Holbrook 2013, 1871); and the *Bataille-Lyotard thesis*, for which 'incommensurability only reveals itself when attempts at communication fail (they often succeed), at which point further communication is possible only through a process of inventing a new language' (Holbrook 2013, 1874).

Here, we will not discuss the differences between the Kuhn-MacIntyre thesis and the Bataille-Lyotard thesis—differences which seem to be about how to respond to incommensurability, whether by second-language learning or through the construction of a new language. For the purposes of this article, it is enough to focus on what these two theses have in common: that is, incommensurability.

The incommensurability thesis allows us to shed some light on what the popular view on interdisciplinarity cannot explain. It allows us to appreciate the fundamental differences of scientific disciplines; to regard 'integration' as something more than the sum of different parts; and to consider those cases in which interdisciplinary interactions do not lead to integration, and even to understand the reasons for when interdisciplinarity fails.

These ideas can be better explained by looking at some recent ethnographical and philosophical studies of interdisciplinarity, which show that putting different specialists at work for the resolution of some common problems is not an innocent operation. In the interdisciplinary practice, in fact, scientists adapt their skills to a set of problems, with problems as well as scientists skills needing to be re-shaped accordingly.

In a study conducted on groups working in integrative systems biology, an emerging field which seeks the integration of computation and engineering modelling with biological experimentation, MacLeod and Nersessian (2016) observe that:

> Modelers are not trained as systems biologists, but as a kind of engineer (e.g. electrical or telecommunications) and thus prior knowledge often will not help them deal with these uncertainties. The importance of their background is not their knowledge of specific engineering systems, but rather their particular approach to problem solving which their reference as the ability to 'think systematically' and 'debug problems'. This enables them to cope with lack of routines and unstructured task environments. Epistemic values that favor precision and exactness that come with handling engineered systems have to be transformed when dealing with 'messy' biological systems. (MacLeod and Nersessian 2016, 407)

As MacLeod (2018) explains, deeper cognitive reasons may hamper interdisciplinarity. This is because one of the consequences of disciplinarity is the development of *domain-specific expertise*. Because of their domain-specific preparation, scientists from different disciplines may encounter serious difficulties in an interdisciplinary setting. Some practices may be too opaque for the outsiders of a particular domain. Furthermore, scientists coming from different fields and trained to the resolution of different domain-specific problems may experience conflicts in the application of some epistemic values for choosing the best problem-solving approach. Finally, the very ways in which the problems to be solved are defined and framed in an interdisciplinary environment may remain vague for a long time.

Another consequence of disciplinarity is a strong sense of *epistemic identity* (Osbeck and Nersessian 2017). On the one hand, epistemic identities shape and influence the cognitive practices of the members of the same discipline; on the other hand, they may create obstacles for the collaboration of scientists coming from different scientific communities. Three points deserves to be highlighted. First, we are not just assuming the existence of incommensurability. Rather, incommensurability is a hypothesis we are making on the basis of the empirical evidence collected in the course of several empirical studies— such as the five-year ethnographic study of two systems biology labs, conducted by Nancy J. Nersessian and her team, which have produced, among other things, the studies cited in the previous paragraphs.

Second, in these studies, integration appears to exceed the sum of different elements. Far from being an activity in which different pieces of knowledge somehow interlock with one another, interdisciplinarity looks more like a transformative activity, in which the actors involved have to modify some of their beliefs, adapt their knowledge and devise new problem-solving methods.

Third, we claim that what emerges from these empirical studies is something closer to Kuhn's early formulation of the incommensurability thesis. As mentioned in section 2, in The Structure of Scientific Revolutions, the incommensurability thesis describes the disparity not only between theoretical languages, but also between problem-solving methods, values, and research agendas. In its early formulation, that is, the incommensurability thesis seemed to capture more of the actual problems that scientists encounter in scientific practice.

The problem faced by interdisciplinary research is that finding a way to communicate across specialties may be necessary but not sufficient for successful problem-solving. Scientists from different disciplines may understand each other's theoretical language and communicate with one another with not too many problems. This does not mean, however, that they will all agree about the methods to employ and the problem-solving strategies to implement. This is all the more evident in those cases in which the knowledge and expertise to be integrated is not only theoretical, as in the example of Andersen and Wagenknecht discussed in the previous section, and in which interdisciplinary collaborations involve theoreticians, on the one hand, and experimentalists, on the other hand.

Holbrook (2013) has developed some philosophical models of interdisciplinarity that take into account incommensurability; the Nersessian team has produced empirical evidence of the difficulties of interdisciplinary collaboration, but without invoking the concept of incommensurability. In this section, we have used the results of the latter to provide empirical evidence for the philosophical models of the former. This has been done by considering interdisciplinary research as an instance of scientific change in which, as explained in section 4, different disciplines become incommensurable when they converge towards the same area of investigation.

6. Concluding Remarks on Incommensurability and Scientific Change(s)

We have considered both specialisation and interdisciplinarity as types of scientific changes subjected to incommensurability. On doing so, we have also attempted to correct some of the misconceptions about the incommensurability thesis. In this concluding section, we want to highlight some of the aspects of the incommensurability thesis which we have brought up in this article.

To begin with, 'incommensurability' is not the same thing as mere 'difference'. Incommensurable paradigms are in a state of competition and the results of this competition cannot be decided objectively, because there is no absolute method to guide scientists in their choices. Different disciplines, by contrast, do not compete, because they are about different domains of investigations. That incommensurability cannot be reduced to differ- ence complicates the assessment of its role in specialisation and interdisciplinarity, which are, respectively, the proliferation, on the one hand, and the convergence, on the other hand, of different disciplines. As we argued, however, if specialisation and incommensurability are considered from a dynamic/historical perspective, and as processes unfolding through time, then the role incommensurability plays in both processes, when it plays it and which obstacles it may create appear clearer.

We have also endorsed Kuhn's early version of the incommensurability thesis, con taining not only semantic but also methodological and cognitive/perceptual aspects. One may wonder whether there would be much value remaining in the incommensurability thesis if it is expanded to include such a wide range of (methodological, cognitive, perceptual) disparities. Perhaps, one of the reasons for why philosophers (and Kuhn himself) went for a more restricted semantic notion of incommensurability is that it is a less vague and more analysable and relatively constrained notion. This point forces us to consider what do we expect from the incommensurability thesis (and, in general, from philosophy of science).

Kuhn abandoned the heavily criticised concept of a 'paradigm' and focused on the philosophical more familiar (but not necessarily clearer) concept of a 'scientific theory'. As a consequence, incommensurability ceased to be 'the lack of a common measure between paradigms' and became 'the lack of a common language between some restricted parts of two scientific theories'. That the semantic version of incommensurability is more precise does not imply that it is also more adequate to capture some of the fundamental problems arising in the complex and multi-faceted practice of science.

As said in section 2, when Kuhn and Feyerabend introduced the incommensurability thesis, they used 'incommensurability' in a metaphorical way. Indeed, one of the difficulties with the incommensurability thesis is trying to understand what the 'lack of a common measure' exactly amounts to and which entities lacking such a common measure precisely are. Scientific activity not being a monolith, it may be that the relata of incommensurability are different from case to case: sometimes incommensurability is the lack of a common conceptual system, other times of a common way of applying scientific values, and so on. Yet, the relation of incommensurability always expresses fundamental disagreements on how to conduct science. The multi-faceted nature of incommensurability reflects the complex nature of science.

At this point, it is crucial to stress that incommensurability is not being expanded to the point of including any sort of disparities whatsoever. Disagreement is often endemic to scientific research. While in a situation of 'normal research' disagreements can be more or less easily resolved, the type of disagreements incommensurability gives rise to lead to non-cumulative changes. In Structure, Kuhn examined only one type of non-cumulative changes: the so-called scientific revolutions. However, the ontological fragmentation accomplished by specialisation and the integration of part of different disciplines occur- ring via interdisciplinarity can also be regarded as non-cumulative changes driven by incommensurability.

Finally, it should not be forgotten that, in *The Structure of Scientific Revolutions*, Kuhn used the incommensurability thesis within a theory of scientific progress, in which science is described not as tending towards an ultimate truth but, rather, as being pushed from behind by its previous accomplishments and failures. Whether science does get closer to the truth is an issue that, like scientific change, tends to be considered from a merely inter-disciplinary perspective. This article has offered a systematic analysis of the relation between incommensurability, specialisation, and interdisciplinarity. Whether the processes of specialisation and interdisciplinarity can shed some new light on the issue of scientific realism is something to be destined to future work.

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