A Family Resemblance Approach to the Nature of Science for Science Education

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Abstract Although there is universal consensus both in the science education literature and in the science standards documents to the effect that students should learn not only the content of science but also its nature, there is little agreement about what that nature is. This led many science educators to adopt what is sometimes called "the consensus view" about the nature of science (NOS), whose goal is to teach students only those characteristics of science on which there is wide consensus. This is an attractive view, but it has some shortcomings and weaknesses. In this article we present and defend an alternative approach based on the notion of family resemblance. We argue that the family resemblance approach is superior to the consensus view in several ways, which we discuss in some detail.

1 Introduction

Although there is universal consensus both in the science education literature and in the science standards documents to the effect that students should learn not only the content of science but also its nature, there is little agreement about what that nature is (see, for instance, Osborne et al. 2003; Smith and Scharmann 1999; Stanley and Brickhouse 2001). Spelling out the nature of science (NOS for short) has met a major difficulty, which we might call the problem of definition or demarcation, for convenience: all attempts so far by philosophers, historians, sociologists of science and science education theorists to define science rigorously or to give a precise demarcation criterion have failed (Alters 1997; Laudan et al. 1986; Ziman 2000). Science is so rich and so dynamic and scientific disciplines are so varied that there seems to be no set of features that is common to all of them and shared only by them. Just consider all the things that scientists do (observing,

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experimenting, model building, testing and so on) and all the disciplines that fall under the concept of science (physics, chemistry, biology, geology, zoology, botany and so on, not to mention all their sub-disciplines). To characterize the necessary and sufficient conditions for being a science in a way to do justice to this richness and complexity turned out to be quixotic. The challenge, therefore, is how to do justice to the richness of science, its dynamic character and the variety of scientific disciplines.

The problem is exacerbated by the fact that philosophy thrives on differences, and as Vladimir Lenin shrewdly put it, “philosophy divides!” Indeed, today philosophical views regarding various aspects and characteristics of science by relevant expert communities show a bewildering array of disparity and no sign of convergence. If anything, there is more divergence than ever before. There are raging disputes among realists, empiricists, constructivists, feminists, multiculturalists and postmodernists about the nature of science. Nor does it help to turn to scientists themselves who hold either rather naïve or else surprisingly diverse views in this regard (Pitt 1990; Shapin 2001).

What then should be done? A promising approach is what might be called “the consensus view”. According to the consensus view, which we owe to Norman Lederman and his collaborators more than others, we should teach students only those characteristics that are widely accepted either in the science standards documents and/or in the philosophy, history, sociology of science and science education literature and for that reason that are the least controversial aspects of the nature of science. The aim is to provide a general understanding of what sort of an enterprise science is, an understanding that is relevant and accessible to advanced secondary school (typically, K-12) as well as college students. This view seems to have gained a good deal of currency in recent years (Abd-El-Khalick 2004; Bell 2004; Cobern and Loving 2001; Flick and Lederman 2004; Hanuscin et al. 2006; Khishfe and Lederman 2006; Lederman 2004; McComas et al. 1998; McComas and Olson 1998; Osborne et al. 2003; Smith and Scharmann 1999; Ziedler et al. 2002). Notice that instead of addressing the major difficulty mentioned above directly, the consensus view tries to get around it by appealing to whatever consensus there is regarding NOS among relevant expert communities.

According to the consensus view, the following characteristics of science are largely agreed upon, provided they are described at some level of generality: scientific knowledge is empirical (relies on observations and experiments), reliable but tentative (i.e. subject to change and thus never absolute or certain), partly the product of human imagination and creativity, theory-laden and subjective (that is, influenced by scientists’ background beliefs, experiences and biases) and socially and culturally embedded (i.e. influenced by social and cultural context). Finally, there is no single scientific method that invariably produces secure knowledge. To this list the following are also added often: science is theoretical and explanatory; there is a distinction between observing and inferring, and between laws and theories; observations are theory-laden; scientific claims are testable and scientific tests are repeatable; and, finally, science is self-correcting.

While we have no objection to this list, provided the items in it are properly understood, we believe that the consensus view has certain shortcomings and weaknesses. First of all, it portrays a too narrow image of science. For example, there is no mention of the aims of science or methodological rules in science. The issue of methodology seems to be dismissed altogether by saying that there is no single method for doing science. While it is certainly true that there is no single scientific method in the sense of a mechanical procedure that determines knowledge production step by step, there are general methodologies (such as the hypothetico-deductive method of testing) and methodological rules (such as those that tell us to avoid making ad-hoc assumptions to save theories from refutation) that guide scientific practice in general ways. Moreover, without the idea of a scientific method or methodological rule, it is difficult to see how science can be self-corrective and provide reliable knowledge. In a similar vein, most of the items in the list pertain to scientific knowledge, and scientific inquiry, by which scientific knowledge is produced, are deliberately left out since it is believed that "NOS refers to the epistemological underpinnings of the activities of science", not to the scientific inquiry or processes (Lederman 2004, p. 308). But this way of excluding scientific inquiry from NOS is artificial; after all, scientific inquiry such as data collecting, classifying, analyzing, experimenting and making inferences are all parts of science and *this fact itself* should be included in NOS. In other words, even though data collecting, classifying, analyzing, experimenting, inferring and the like are themselves skills that students must acquire for doing science, the fact that these are all activities that follow certain guidelines and have certain aims is itself a fact about the nature of science that students should learn as part of NOS. In Sects. 3 and 4 we will say more about the relationship between such activities and various aims of science.

Second, the consensus view portrays a too monolithic picture of science and is blind to the differences among scientific disciplines. For example, astronomy and cosmology are very different from, say, chemistry in that they are non-experimental disciplines. Relatedly, under the consensus view, NOS appears as fixed and timeless. It gives the students the impression that science has no history and no room for change in its nature. However, history of science teaches us that its nature did change and evolve, albeit slowly. For example, more and more disciplines became mathematical in time and new methodological rules have been added to the stock of science. We will discuss these aspects of science in more detail in the next section.

Finally, the items mentioned in the consensus view seem to lack sufficient systematic unity and certain issues they give rise to are not sufficiently noticed or addressed. More specifically, it is not clear how they hang together as there appear to be some tensions among them. For instance, scientific knowledge is said to be theory-laden and subjective. Does this make objectivity of science impossible? If not, why not? If science is socially and culturally embedded, how is it that it produces knowledge that is valid across cultures and societies? Is the influence of society on science good or bad? How do we distinguish between these two kinds of affects? Does science have any means of detecting the bad ones and eliminating them? These are important questions that need to be raised if we want our students to have a sophisticated understanding of NOS.

Is there a view of NOS that overcomes the major difficulty of definition and demarcation, a view that does not have the limitations and weaknesses of the consensus view? We believe there is, and in this article we present and defend one, which we call "the family resemblance approach". We claim originality neither for the idea of family resemblance nor its application to science. As is well known, the idea of family resemblance was originally developed by Wittgenstein (1958) to solve the perennial problem of universals in philosophy and put to use for explaining the unity of science despite its diversity by several other philosophers (see Hacking 1996; Eflin et al. 1999). In this paper we develop this approach further to present a rich picture of the nature of science for the purposes of science education and show that it is a powerful alternative to the consensus view. We shall explain the meaning of family resemblance in detail in Sect. 2. In Sect. 3 we apply the idea of family resemblance to science and develop the family resemblance approach further. In Sect. 4 we show that the family resemblance approach has a number of virtues that the consensus view lacks. We claim that the family resemblance approach is more comprehensive and systematic than the consensus view. It covers all general, structural aspects of science and provides a novel way of capturing the unity of science while doing justice to its diversity. It is also pedagogically very useful. We discuss how the family resemblance approach can be applied in the classroom in Sect. 5. We conclude our paper with some general remarks.

2 The Idea of Family Resemblance

What might a family resemblance definition of the term ‘science’ be like? As befits the idea of family resemblance there is no one definition of it but a cluster of related notions. Certainly they all stand in contrast to the kind of definition that sets out necessary and sufficient conditions for a term to be defined. Thus the term ‘triangle’ can be defined explicitly as: a closed plane figure with three straight sides. This not only gives six characteristics which specify the necessary and sufficient conditions for being a triangle, but also determines the “essence” of being a triangle or the analytic meaning of the term ‘triangle’. However, as Wittgenstein pointed out, this kind of definition cannot serve to define all terms (Wittgenstein 1958, sections 66–71). His classic counterexample is that of a game. Any attempt to define the term ‘game’ must include games as different as ball games, stick games, card games, children’s games that do not involve balls, sticks or cards (such as tag or hide-and-seek), solo games (hop-scotch), mind games, and the like. Unlike the term ‘triangle’, there is no fixed set of necessary and sufficient conditions which determine the meaning of ‘game’. Whether or not this is correct in the case of the word ‘game’ is open to dispute (see Searle 1995, p. 103). However this issue might be resolved, there might still be other cases where the family resemblance idea gets some traction, as we think it does in the case of ‘science’.

The basic idea of a family resemblance definition turns on the fact that the members of a family can each resemble one another in some respects but not in others. The problem here is to say in what way the network of characteristics can form a family on the basis of resemblances. The anthropologist Rodney Needham makes a number of suggestions as to what this might be, two of which we will mention here and adopt the second (Needham 1975). The first kind of family resemblance Needham calls ‘serial likeness’, which is illustrated as follows: individual 1 has characteristics P, Q, and R; individual 2 has characteristics R, S and T; individual 3 has characteristics T, U and V. This can be a simple model of descendants in a family in which individual 1 shares characteristic R with offspring 2 but does not share other characteristics; similarly with 2 and 3 who share characteristic T but not others. However, individual 1 shares no characteristic with the more remote descendant individual 3, though they can be deemed to be members of the same family. As useful an account this might be of one kind of family resemblance, it will not serve our purposes as well as a second “polythetic” model that Needham suggests, which we introduce below.

Consider a set of four characteristics {A, B, C, D}. Then one could imagine four individual items which share some three of these characteristics taken together such as (A&B&C) or (B&C&D) or (A&B&D) or (A&C&D); that is, the various family resemblances are represented as four disjuncts of conjunctions of three properties chosen from the original set of characteristics. This example of a polythetic model of family resemblances can be generalised as follows. Consider any set S of n characteristics; then any individual is a member of the family if and only if it has all of the n characteristics of S, or any $(n - 1)$ conjunction of characteristics of S, or any $(n - 2)$ conjunction of characteristics of S, or any $(n - 3)$ conjunction of characteristics of S, and so on. How large n may be and how small $(n - \mathrm{x})$ may be is something that can be left open as befits the idea of a family resemblance which does not wish to impose arbitrary limits and leaves this to a "case by case" investigation. In what follows we will employ this polythetic version of family resemblance in developing our conception of science.

Before doing this there is a limiting case to consider. Suppose an example like that above but in which there is a fifth characteristic E which is common to all the disjunctions of conjunctions as in the following: (A&B&C&E) or (B&C&D&E) or (A&B&D&E) or (A&C&D&E). Would this be a violation of the kind of family resemblance definition that Wittgenstein intended? Not necessarily. We might say as an example of characteristic E in the case of games that games are at least activities (mental or physical). Nevertheless, being an activity is hardly definitional of games nor does it specify a criterion of demarcation; there are many activities that are not games, such as working or catching a bus.

We will see in the case of science that there are characteristics common to all sciences, but are such that they cannot be definitional of it. They cannot be used for demarcating science from other human endeavours either. An example would be observing. We cannot think of a scientific discipline which does not involve making or relying on observations at some point. But then not everything that involves observing is a science (such as crossing a road in heavy traffic, train spotting or conducting an orchestra). The situation in science is actually a bit more complex than this. We need to take into account the "observings" made by detecting devices of various sorts. Such is the case in remote sensing satellites which record features of the earth's surface (vegetation, water) or in balloons sent aloft to detect levels of ozone in the stratosphere. These devices collect relevant data, but no human observation need be involved. Looked at in this way, human observation is a species of the more generic data collecting by a range of detecting devices (humans being only one kind of detecting device).

Again we cannot think of a science that does not involve making some kinds of inference at some point; if it did not it would not get beyond naive fact collecting. Nevertheless, as before, inferring, though common to the sciences, is not exclusive to them. Judges in a court or speculators on the stock market make inferences as well, but they are not doing science. Note that inferring can be quite generic since the sciences might differ according to the kinds of inferences they make: to name a few, there are inductive, deductive and abductive inferences.

In the light of these points we can say that there are a few core characteristics that all the sciences share (data collection and inferences, for instance), but they are not sufficient either to define science or to demarcate it from other human endeavors. It is the other characteristics that accompany observing and inferring that make an important contribution to the family-forming characteristics that characterize scientific disciplines, as we will go onto explain.

3 The Family Resemblance Approach to the Nature of Science

There are many items called 'science', ranging from archeology to zoology. (Here we will exclude the special case of mathematics from our discussion because of its non-empirical character.) So what do these many sciences have in common? The idea of family resemblance will tell us that this is a wrong question to ask. What we need to do is investigate the ways in which each of the sciences are similar or dissimilar, thereby building up from scratch polythetic sets of characteristics for each individual science.

Consider how widely shared are some of the characteristics of science. Begin with observing and experimenting. Although most sciences are experimental, a few are not.

Astronomical theories (before the advent of radio "telescopes") appeal to human telescopic observations, but astronomy is not an experimental science; experiments are simply not possible in this field. Again consider the characteristic of making predictions. Again, most sciences aim to make predictions, especially novel predictions, but not all of them succeed. For example, celestial mechanics is very good indeed in predicting planetary positions. In contrast, even though evolutionary biology does a wonderful job of explaining the evolution of species, it has not produced any mathematically precise, novel predictions. Similarly, earthquake science does a good job of explaining why earthquakes occur, but so far it has failed to predict the times of major earthquakes, though it is pretty successful in predicting their locations. Nor is earthquake science a directly experimental science; we do not experiment by manipulating earthquakes (though there are elaborate techniques for seismic detection which are not strictly experimental in the sense we intend). Particle physics, by contrast, is both an observational and experimental science and is very good at both explaining and predicting many subatomic phenomena.

Let us now explore the similarities and differences among various scientific disciplines in terms of methods and methodological rules they use. Often the hypothetico-deductive method is employed, in many sciences, by drawing out predictive consequences of theories and then checking those predictions against observational or experimental data. Random sampling might also be used for testing, but note that there is no role for randomized double-blind experiments in physics. In contrast in evidence-based clinical medical science the hypothetico-deductive method appears not to be of common use, while the methods of randomized double and even triple blind experiments are the ubiquitous golden standard for testing.

In the above we have mentioned a number of individual sciences (astronomy, physics, evolutionary biology, earthquake science, and medical science) and a number of characteristics (observation, experimentation, prediction, hypothetico-deductive testing; random testing, and blinded randomized testing). As can be seen for any chosen pair of these sciences, one will be similar to the other with respect to some of these characteristics and dissimilar to one another with respect to other characteristics. If we think of these characteristics as candidates for defining science, then no necessary and sufficient definition would be forthcoming. If we take a family resemblance approach, however, things look very different and promising. Indeed, there are a number of similarities, crisscrosses and overlaps among these scientific disciplines, which give them sufficient unity. This is fleshed out further in what follows.

Having described the family resemblance approach to the nature of science with some concrete examples, we are now in a position to present a structural characterization of NOS and exemplify the family resemblance approach in terms of it. This enables us to see how the family resemblance approach to NOS works more systematically and clearly. As we shall see in Sect. 5, this way of using the family resemblance approach to science is also pedagogically very useful.

Above we have seen that there are a number of similarities and differences among scientific disciplines in terms of whether they rely only on observations or also make use of experiments, in terms of whether they succeed in making quantitatively accurate predictions or not, and in terms of the methodological rules they employ. These can be classified in a systematic way in terms of the following categories that give us a structural description of NOS: (1) activities, (2) aims and values, (3) methodologies and methodological rules, and (4) products. These categories are naturally suggested from our discussion so far. Here is how (for a detailed discussion of them see Nola and Irzik 2005, chapters 2, 4, 6 and 10).

3.1 Activities

Observing and experimenting are clearly scientific activities, hence the category 'activities'. As we have pointed out before, when described at a very general level, observing will be an activity common to all sciences. However, it should be noted that observational practices will obviously vary according to the scientific discipline in which observation is carried out. For example, specific observational skills are required in observing the planets and stars using telescopes; they involve being able to position the heavenly bodies against the cross-wires of a telescope while simultaneously noting the time on a clock to avoid the biases associated with what is known as an observer's 'personal equation'. These are quite different from the recognitional skills of, say, fossil prospectors in Northern Kenya and Ethiopia who become very good indeed in identifying fossils on the ground from other rocks. In fact some are so skilful that, as Richard Leakey says, they can recognize a fossil as that of say, "part of the upper forelimb of an antelope" (Leakey 1981, p. 39).

Further, there are the different activities of collecting and classifying the objects one observes as in, say, systems of plant and animal classification. Calibrating scientific instruments and planning, setting up and carrying out experiments, which we may call 'material practices', require a range of quite different of skills that vary according to each kind of experimental science. Much more general cognitive activities include the important task of formulating and posing questions or problems in each of the sciences and then finding solutions to them. Importantly, posing problems and searching for solutions are one of the drivers of scientific activity noted by philosophers of science such as Kuhn and Popper. Also central are activities such as formation of new concepts (such as "field" and "gene"), inventing (or constructing) hypotheses, theories or models to solve problems. Some of these activities will involve the use of mathematical skills, ranging from the proper methods for applying equations of dynamics to some concrete case of motion such as a swinging pendulum. For convenience, we may call them 'mathematical practices'.

To sum up, there are a set of activities that are characteristics for some sciences but not others, thereby forming a family resemblance set. These include observational practices, material practices, mathematical practices and so on. Looked at broadly all sciences will have observational practices (more broadly, data collection practices), but from a more fined grained point of view, the observational practices involved in, say, astronomy will not be the same as in ethology or archeology. Again, physics will involve both material and mathematical practices extensively, while for botany there are classificatory practices but there is little, if at all, mathematical practices. And so on for all the individual sciences; each will draw on some sub-set of characteristics but not others.

3.2 Aims and Values

Being able to make predictions and providing explanations are among the well-known aims of science, so we obtain the second category of aims. The aims in question are not moral but cognitive. Of course, there are many other aims in science such as consistency, simplicity, fruitfulness and broad scope (Kuhn 1977); high confirmation, as emphasized by logical empiricists (Hempel 1965, Part I); falsifiability and truth or at least verisimilitude (i.e. closeness to truth) (Popper 1963, 1975); empirical adequacy (Van Fraassen 1980), viability (Von Glasersfeld 1989), ontological heterogeneity and complexity, as emphasized by empiricist feminists like Longino (1997).

As is evident, there need not be agreement as to which of these aims are to be adopted for the various sciences. Differences in values in the sciences usually arise from differences in the philosophical understandings of theories. Thus, scientific realists, such as Karl Popper, say that science aims for truth (or verisimilitude) not only at the level of the observable but also at the level of unobservables; realists think we can get truths about the hidden structure of the world. A number of anti-realists object to this with varying degrees of vehemence. Radical constructivists in science education, such as Von Glasersfeld (1989), wish to replace the idea of our scientific theories approaching the truth about the world with the idea of our conceptual structures being viable. While Thomas Kuhn advocates observational accuracy (and therefore truth at the level of observables) as a value, he rejects the idea of truth at the unobservable level, saying "the notion of a match between the ontology of a theory and its "real" counterpart in nature seems to me to be illusive in principle" (Kuhn 1970, 206). Constructive empiricists such as Van Fraassen (1980) reject the idea that "science aims to give us, in its theories, a literally true story of what the world is like" (p. 8) and replace it by the aim "to give us theories which are empirically adequate" (p. 12), that is, the constructive empiricist aim is to get theories (or models) to fit all observations and nothing more. Finally, the scientist Pierre Duhem expressed the influential view that the aim of physical theories is not "the *explanation* of a group of laws experimentally established" but rather "the aim is to *summarise* and *classify logically* a group of experimental laws without claiming to explain these laws" (Duhem 1962, 7). Moreover, some of the aims advocated by various philosophers are directly opposed to one another; for example, Longino's insistence on ontological heterogeneity and complexity clashes with Kuhn's simplicity.

Though we have our own views about these varying aims for science, the family resemblance view of the sciences we are advocating here does not require us to take sides in these disputes. Rather, it merely requires that we set out what are the aims that individual sciences can have under various philosophical stances or interpretations of them and the role they may or may not have in any characterisation of a particular science. Thus, for example, a scientific realist interpretation of scientific theories will share truth at the observable level as an aim of science with a constructivist empiricist or a Kuhnian interpretation, but differ from them at the unobservable level; similarly, scientific realists and constructivist empiricists will agree that explanation is an aim of science, but Duhemians will disagree; and so on. In this way, we will have a family resemblance with respect to the aims of science according to different philosophical interpretations or stances.

Before we proceed to the next category, we would like to point out that the aims of science are also regarded as (cognitive) values since scientists value them in the sense that they desire their hypotheses, theories and models to realize them (Kuhn 1977). It is also to be noted that values in science also function as criteria for theory choice and can be expressed as methodological rules. Take, for example, the value of simplicity. We can write this as the rule: given two rival theories, other things being equal, choose the simpler theory. Similarly, the value explanatoriness gives the following criterion for theory choice: given two rival theories, other things being equal choose the theory that is more explanatory. This brings us to the next category of methodologies and methodological rules.

3.3 Methodologies and Methodological Rules

Science does not achieve its various aims in a haphazard way, but employs a number of methods and methodological rules. These constitute a third important category, reflecting the nature of science. Historically there have been proposals about scientific method from Aristotle, Bacon, Galileo, Newton, Whewell, and Mill—not to mention the many theories of method proposed in the twentieth century by philosophers, scientists and statisticians.

For many of these philosophers, deductive, inductive and abductive reasoning form an important part of any kind of scientific method. Additional methods for testing hypotheses include a variety of inductive and statistical methods along with the hypothetico-deductive method. The latter is a broad schema in which, simply described, hypotheses are proposed and applied to specific situations; from these are deduced test consequences, such as predictions, which are then compared with observations and experiments to see if the test consequences pass or fail. Such a method can be generalized when considered within a Bayesian context. Many examples of scientific methodologies can be found in science (see Nola and Sankey 2007; Nola and Irzik 2005, chapters 7–9).

The idea of scientific methodology also includes methodological rules as discussed by a number of philosophers of science such as Popper (1959) and Laudan (1996). Science is replete with such methodological rules. Some are controversial but others are generally accepted. Here are some examples of the kinds of rules that are said to be an important part of scientific methodology:

- construct hypotheses/theories/models that are highly testable;
- avoid making *ad-hoc* revisions to theories;
- other things being equal, choose the theory that is more explanatory;
- choose the theory that makes novel true predictions over the theory that merely predicts what is already known;
- reject inconsistent theories;
- other things being equal, accept simple theories and reject more complex ones;
- accept a theory only if it can explain all the successes of its predecessors
- use controlled experiments in testing casual hypotheses;
- in conducting experiments on human subjects always use blinded procedures.

Many advocates of the consensus view are dismissive of scientific methodology or methodological rules. They say that there is no algorithm, no fixed and universal set of rules that govern scientific activity at every stage of inquiry. This is certainly true, a point made forcefully by Paul Feyerabend in his book *Against Method* when he said "anything goes" (Feyerabend 1975, 28). However, there is no reason to understand scientific methodologies such as various forms of inductivism, hypothetico-deductivism and Bayes' Theorem and its associated methods in this strict manner. Although they certainly capture something deep about the nature of methods employed in science, it should not be forgotten that they are highly idealized, rational constructions. As such, they cannot faithfully mirror what scientists do in their day-to-day activities, nor can they always dictate to them what to do at every step of their inquiry; but they can often tell them when their moves are not rational. Nevertheless, they do explain (at least partially) the reliability of scientific knowledge and how it is that science eliminates its errors. Without the notion of scientific method and methodological rules, the self-corrective nature of science becomes a mystery.

We presented the above rules of method as if they are categorical imperatives. This needs to be qualified in two ways. The first is that some of the rules can, in certain circumstances, be abandoned. Spelling out the conditions in some antecedent clause in which the rules can be given up is not an easy matter to do; so such rules are best understand to be defeasible in unspecified circumstances. The second is that such categorical rules ought to be expressed as hypothetical imperatives which say: rule R ought to be followed if some aim or value V will be (reliably) achieved (see Laudan 1996, chapter 7). Often reference to the value is omitted or the rule is expressed elliptically. For example, the rule about ad-hocness has an implicit value or aim of high testability. So, more explicitly it would look like: "If you aim for high testability, avoid making ad-hoc revisions to theories." If rules are understood in this way, then the link between the methodological rules of category 3 and the aims of category 2 becomes clearly visible.

Now, do all sciences employ all of these methodologies and methodological rules? Although all of them appeal to one or another methodology and most of the methodological rules are common in many of them, there are nevertheless some differences among them. For example, as we pointed out earlier, there is no role for randomized double-blind experiments in non-human sciences such as physics, but they are commonplaces in evidence-based medical science involving human subjects. Similarly, the rule that dictates the use of controlled experiments in testing causal hypotheses will be obviously of use only in those scientific disciplines that are experimental. This a feature of science that the family resemblance view can readily accommodate. It is an obvious truism that each individual science will share with some other science some rules of methods and not others; some pairs of sciences might have many such rules in common while other pairs have few. On some definitions of science this becomes a puzzle; but on the family resemblance view that puzzle simply goes away.

3.4 Products

Finally, when scientific activities achieve their aims using the aforementioned methods and methodological rules, they produce a number of results, which we call 'products'. These include hypotheses, laws, theories, and models as well as collections of observational reports or collections of experimental data. The ultimate propositional end product of scientific activities is knowledge or rational belief.

Do all sciences have all of these products? They may all have reports of observations and data, and all of them have taxonomies of objects they study: physics classifies subatomic particles, chemistry classifies elements as shown in elegantly pictured periodic tables, botany classifies plants and so on. Nevertheless, there are important differences in these systems of classification. For example, whereas biology's taxonomies are typically functional in that such biological objects as hearts and kidneys, cells and genes are characterized according to the functions (that is, purposes) they have, chemistry's taxonomy of elements is not functional in the intended sense at all, but is based on properties such as atomic number and weight. Furthermore, not all sciences may have laws. For example, while there are clearly laws in physics, it is a contested issue as to whether there are laws in biology (see Rosenberg 2008). It is not our task to resolve these disputes here. We are content to list those characteristics that we call scientific products and show that they form a family-resemblance set with each science sharing some of them but not others.

The table below summarizes these basic categories reflecting NOS.

Science			
1 Activities	2 Aims & Values	3 Methodologies & Methodological rules	4 Products

In the light of this table, what is the set S of elements that make up the characteristics of science from which polythetic family resemblance definitions of individual sciences can be formed? They are all the elements mentioned under all four categories of activities, aims and values, methodologies and methodological rules and products. A family resemblance definition for an individual science will be formed by taking some subset of all these characteristics, and this may well differ from the subset of characteristics for some other individual science. When considered as pairs of sciences there will be some characteristics held in common and others not held in common.

We can now make the following general points about this table. First, each category is open-ended; that is, the characteristics of science that fall under each category are not fixed, so more may be added. Second, although we think that the four categories we presented are pretty exhaustive, we admit the possibility that other categories might perhaps be added or new categories might emerge as science develops.

Finally, we can now see more clearly that not all scientific disciplines share all of the characteristics listed in all the categories. We conceded they all share observing and inferring, but these are hardly definitional of science, and are not sufficient to demarcate science from other human endeavours. Hence, leaving aside these two common activities, we see that sciences share some or most of the characteristics under each category but not all, so they are similar with respect to some characteristics but dissimilar with respect to others. Nevertheless, given any two disciplines taught in science courses, there are sufficient similarities, overlaps and crisscrosses that make them both “sciences”. To put it differently, what unites diverse disciplines from physics to earth sciences, from cosmology to life and environmental sciences is the family resemblance between them with respect to the characteristics within each category.

4 Virtues of the Family Resemblance Approach

In this section we show that the family resemblance approach to NOS has none of the weaknesses and shortcomings of the consensus view. Quite to the contrary, it has a number of advantages over it as a characterization of NOS. It is more comprehensive than the consensus view, and indeed, almost all of the items listed in the consensus view can be derived from it.

The first point that emerges from our characterization of science in terms of the family resemblance approach is its empirical nature. This is a direct consequence of the cooperation between the aim/value of testability and the activity of observing (and also experimenting, if possible). A testable theory is one which can be checked against observations or the results of experiments. That is what gives science its empirical nature. Results of observation and experiments also provide evidence for or against scientific theories; in other words, science is evidence-based.

Second, we can clearly see that science is a special form of *critical* inquiry. Theories and hypotheses that are put forward are subjected to empirical scrutiny using various methodologies and methodological rules. As a result of this scrutiny, certain theories may be revised or abandoned completely. To put it differently, science has a self-correcting mechanism by which it eliminates errors and falsehoods. This is not to say that individual scientists may never be biased or influenced, in their scientific work, by personal, social and economic interests or social, cultural and historical milieu. However, such biases and influences, to the extent to which they distort scientific findings, are likely to be spotted and eliminated by the open and free discussion among the members of the scientific community by appealing to the observational reports, experimental data, methods and methodological rules, which collectively secure the critical function of science. This is an important aspect of NOS which is missing in the consensus view.

Third, reliability and objectivity that are generally attributed to science are also related to this last point. Scientific knowledge, though theory-laden, is nevertheless reliable because it is obtained by subjecting our theories to critical scrutiny indicated above. Similarly, the fact that science is objective (in the sense that scientific findings are correct independently of individual, social and cultural variations) is a result of the same inter-subjective critical process. That scientific experiments are reproducible also contribute to the objectivity of scientific knowledge. Whoever does the same experiment under the same conditions should come up with the same result regardless of when and where the experiment is carried out. Again, it is not clear in the consensus view how reliability and objectivity of science is to be explained without such considerations.

Fourth, given the nature of the relationship among data, methodology, and theories (or laws and models) it is easy to see why imagination, ingenuity and creativity play an important role in science. Theories and laws go beyond observational and experimental data and for that reason are not reducible to them. Their inference or construction requires much imagination and creativity since there are no methodologies or methodological rules that mechanically generate them. For these reasons there will always be room for creativity in model building, theory construction and discovering laws in science.

Thus, we see that the family resemblance approach captures the elements of NOS described by the consensus view: that scientific knowledge is empirical, testable, explanatory, objective, reliable, partly the product of human ingenuity and creativity and is self-correcting—all of these follow are accommodated within family resemblance approach.

This is not to say that the family resemblance approach adds nothing new to the consensus view. It contains novel elements and is superior to the latter in several ways, some of which we have indicated above and more can be said. To begin with, the family resemblance approach is more comprehensive than the consensus view. Whereas the latter does not even mention scientific activities, aims/values and is dismissive of scientific methodology altogether, the former includes them and gives a central place to them as significant categories that characterize the nature of science. Moreover, the family resemblance approach weaves these categories in a systematic and integrated way: to put it in a nutshell, according to it, *science is a cognitive system whose investigative activities have a number of aims that it tries to achieve with the help of its methodologies and methodological rules, and when successful, produces a number of outcomes, ultimately, knowledge*.

Another attractive feature of the family resemblance approach is that it does justice to the differences among scientific disciplines, a diversity to which the consensus view is blind, and yet it explains their unity by emphasizing the partial overlaps and similarities among them. It is these that justify the label ‘science’ that we apply to various disciplines from archeology to zoology, even though there is no common set of characteristics shared by all of them and only by them. In this way, the family resemblance approach solves, or more correctly, dissolves the problem of definition and demarcation.

Finally, whereas the consensus view presents a frozen picture of NOS, the family resemblance approach captures the dynamic and open-ended nature of science. It recognizes the fact that as science develops it may, and indeed often does, acquire new characteristics. For example, from a historical perspective we see that many scientific disciplines such as physics, chemistry, electricity and magnetism became mathematical only after their respective scientific developments in the 18th and 19th centuries. Similarly, the hypothetico-deductive method was first clearly formulated and became established during the same period. New methodological rules like the one that tells the scientist to use blind procedures in conducting experiments on human subjects in life sciences came about only in the twentieth century. The family resemblance approach therefore does justice to the historical development of science and underlines its dynamic, open-ended nature.

5 The Family Resemblance Approach in the Classroom

We believe that the family resemblance approach can be used in a pedagogically effective way in the classroom to teach the students the nature of science provided they already have sufficient exposure to science. For instance, the teacher may begin by asking what scientists do. This question is likely to prompt the students to come up with examples that fall under the category "scientific activity". Suppose observing, experimenting and theory building came up. A host of interesting questions can be pursued in this context: Is observing a passive activity? How does observation differ from experimentation? What is the point of doing an experiment and how does it relate to theory? and so on. Next, the teacher may ask what the aim or aims of these activities are. This could be motivated very naturally since everybody knows that virtually all activities have some aim or other. Then, the teacher can further explore the connection between activities and aims. Does this kind of activity reliably achieve that aim? What can go wrong? What can be done? More generally, the teacher may ask how scientists try to achieve their aims. This may lead to the ideas of scientific method and methodological rules. Once the students grasp the categories "activity", "aims" and "method and methodological rule", then the teacher may finally ask: given this sort of activity to realize that aim with the help of such and such method or rules, what is the outcome? This is likely to yield the various elements that we have listed under the category "products", depending on the nature of the activity. In this way students can appreciate how various aspects of science form a tightly integrated whole.

The family resemblance approach enables the teacher to focus in class on any of its categories if they want to discuss an aspect of science in more detail. Thus, for example, some teachers may wish to emphasize *the aims of science* and discuss what they are and their functions. They may also wish to bring to the students' attention that these are not necessarily identical with *the aims of scientists*. Scientists are human beings, and, *qua* being humans they may be motivated by all kinds of non-cognitive goals in practicing their trade, such as curiosity, fame, and benefiting society. The teacher can then ask students what types of relationships there are or might be between the aims of science and those of the scientists.

Yet other teachers may wish to emphasize the nature and plurality of methodologies in science: simple enumerative induction, eliminative induction, simple and sophisticated versions of hypothetico-deductive method, and various methodological rules we have introduced earlier. Discussion of methodologies and rules give the teacher the opportunity to draw attention to the plurality of methods used in science. A discussion about the nature of these methods may lead the students to appreciate the fact that scientific methods and rules are not mechanical procedures that generate theories from data. To this end, they may be invited to come up with different hypotheses that fit or explain the same data. This naturally gives rise to the idea that science is a creative activity. Alternatively, one may explore the connection, emphasized by Karl Popper in his falsificationist methodology, between the methodological rule that demands avoiding *ad-hoc* revisions and achieving the aim of testability.

The topic of methodology and methodological rules is also very fruitful for raising some important questions in the classroom such as the following: How might personal biases creep into scientific inquiry? Is it possible to spot and eliminate them? If so, how? What role do methodologies play here? Or consider the following question: if all scientists follow the same methodologies and rules, how come they sometimes disagree? The exploration of this issue enables the teacher to make several interesting points about the nature of science. These may include the following: (1) Methods are not mechanical algorithms that give a unique output (say, a theory, model or law) when applied to empirical data (evidence) at hand. (2) Empirical data (evidence) are always finite, and theories are sometimes underdetermined by data (evidence). In other words, at a given point in time it may be the case that the same data (evidence) may be explained by two rival theories equally well. In that case, there is a problem of choice. (3) Different scientists may make different choices even if they appeal to other values or criteria (other than empirical evidence) such as simplicity, fruitfulness, broad scope, etc. that they share. This is because they may disagree about which theory is simpler, more explanatory and broader in scope; or it may happen that these criteria point to different directions since one theory may be simpler than another, but the other theory may be more explanatory. If two scientists disagree about the weight of these criteria, they may not choose the same theory (see Kuhn 1977). In this way, students can appreciate the fact that disagreements may (and as a matter of fact do) arise in science, but that these are often *rational* disagreements, not purely subjective or arbitrary.

Focusing on the category of products of science can also lead to insightful discussion. For example, once students recognize that observational or experimental data, hypotheses, theories, knowledge and truth are all among the end products of science and have an idea about the nature of each, they can be prompted to discuss the following questions: what are the possible relationships between a given set of data and a hypothesis (or theory)? This can give rise the idea of evidence that favors (confirms) or undermines (falsifies or refutes) the hypothesis. Suppose that a hypothesis yields one or several predictions all of which are true. Can we infer for sure that the hypothesis in question is true? If not, why not? Can a false hypothesis yield some true predictions? A carefully guided discussion of these and similar questions can easily lead to concepts such as confirmation, falsification, and fallibility of science.

In addition to these, the family resemblance approach gives the teacher the opportunity to draw students' attention to the differences among various scientific disciplines as we pointed out earlier, and it enables the historically minded science teacher to give the students an idea about the historical development of science. For example, she can point out that in ancient times only astronomy aimed at *quantitative* accuracy and not other disciplines such as physics and that one major result of the Scientific Revolution in the sixteenth and seventeenth centuries was the mathematization of many scientific disciplines; as a result, that a theory should make quantitatively accurate predictions eventually became a routine demand from physics, chemistry, electricity, magnetism and so on. Similarly, she can point out that the idea of experiment that we have today was developed again during the Scientific Revolution. In this way, students can appreciate the fact that science has a history.

We think that all of these are important issues about the nature of science that can be discussed, provided we exercise caution and modesty regarding what we can and cannot achieve in the classroom setting (Matthews 1998).

Finally, the family resemblance approach is also attractive because it is philosophically neutral in the sense that it is free of philosophical commitments such as realism, positivism, empiricism, constructivism, and the like. One can adopt any one of these, depending on how one wants to spell out each item that falls under each category of the family resemblance approach. For example, while realist educators may wish to emphasize truth as an aim of science both with respect to observable and unobservable entities, those who are sympathetic to constructive empiricism may settle for empirical adequacy. Similarly, some may choose to discuss the difference between knowledge and mere opinion and define knowledge as justified true belief, or as the outcome of a reliable process, or as “viable constructions”, and so on. Thus, they can add content to the family resemblance approach according to their philosophical orientation or else completely avoid discussing these difficult philosophical issues if they wish to.

6 Concluding Remarks

In this article we presented a family resemblance approach to NOS and argued for its virtues. This approach, we have claimed, goes well beyond existing characterizations of science, especially the consensus view, without suffering from its weaknesses and limitations. It is more comprehensive than the consensus view, captures the dynamic and open-ended nature of science and weaves the relationships among its categories and the various elements that fall under them in an integrated way; yet it is simple enough to be effectively useful for giving students a good idea about the rich nature of science. It enables the teacher to characterize science in a nutshell as follows: *science is a cognitive system or pattern of practice and thought that involves such and such activities; values and aims at such and such; produces so and so using such and such methodologies and methodological rules.* Needless to say, such a characterization is only as good as the use it is put to, and we hope that we provided enough content and detail for it to be informative and enlightening for the purposes of science education.

The attentive reader will notice that we have said very little about the social embeddedness of science. This is because our paper has focused on the cognitive aspects of science. We are well aware that science is at the same time a social institution; it does not exist in a vacuum and all kinds of social, cultural, historical and political factors influence science. None of these facts are incompatible with the family resemblance approach: In fact, to the extent to which part of what it means to say that science is socially embedded is to say that non-cognitive values are operative in science and influence science, it can be accommodated into family resemblance approach by extending the category of values to include non-cognitive values as well. For example, alongside the various cognitive values, Kuhn (1970, 185) suggests the value of social utility and writes: “science should (or need not) be socially useful”. He does not think of this as a value that all sciences ought to exemplify. One of the advantages of the family resemblance approach to aims and values is that social utility is not a compulsory value; it could or could not be included in any cluster of characteristics chosen for science. This consideration opens the door to a wide range of non-cognitive values that are applicable to the scientific enterprise, in particular those advocated by Merton (1973, chapters 12 & 13), These values, which, according to Merton, constitute the ethos of science, are binding not so much on science itself but people who are engaged in science; they are thought of as institutional values of science and include universalism, communalism, disinterestedness and organized skepticism. Once again, on the family resemblance view of science, these are not compulsory characteristics of value to include in any definition of science; but they can become significant characteristics to include in some accounts of what science is. There is much more to be said about this topic and its relation to the other categories of science, but this must wait for another occasion.

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