The Vector of Scientific Disciplinarity: An Exploration of Scientific Disciplines and the Future of Interdisciplinary Research

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The Vector of Scientific Disciplinarity: An Exploration of Scientific Disciplines and The Future of Interdisciplinary Research

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Abstract

The disciplinarity of science and the future of interdisciplinarity in science is deeply connected with understanding the scope of scientific practice as well as the demarcation and organization of scientific disciplines. These topics, explored through the structure of their subjects, theories, methods, and interpretation, lead to the conclusion that science and its disciplines are largely defined by the integration of philosophical principles into the ethos of the practices rather than by any specific criteria. The ways in which different disciplines behave and interpret philosophies impact how those disciplines are organized and categorized, resulting in deep philosophical and perspective divides between disciplines. As a result of these conclusions, it can be asserted that interdisciplinary research faces many challenges. To combat the discipline divides, careful consideration of the philosophical discipline differences and the limited perspective of individual disciplines is required. Additionally, interdisciplinary research might consider viewing the disciplines as philosophically and socially unique, as well as equally valid and scientific, in order to effectively collaborate on interdisciplinary science and continue interdisciplinary science through time.

Introduction

Science has been separated into categories or disciplines throughout its history[1]. The structure of this categorization has taken many forms and the disciplinarity of science has changed with the behaviors and beliefs of scientists and institutions. Through these historical changes some traditional and colloquial disciplines have emerged in a modern conception of science. These disciplines as well as many and various subdisciplines engage with their unique history forming distinct practices and viewpoints. Disciplines' study different subjects, postulate different theories, utilize different methods, and engage in different metaphysical interpretations. Exploration of these disciplines - their function, nature, and historical context - can impact the deeper questions of knowledge, application, and future study. The central questions that this paper attempts to answer are: what is the function of disciplines in science and what is the impact of disciplinarity on the future of interdisciplinary research.

The Vector of Science

Scientific inquiry often involves knowledge being catalogued and inquiry being perpetuated through time with each experiment or study creating new questions for science to explore. Thus, one is led to wonder about the impact of scientific disciplines and of philosophy on future questions, insights, and results. This will, henceforth, be referred to as the *vector of science*. This metaphor will be used throughout this paper to address the conception of science not as a stagnant, singular action, but instead as a temporal, impacted practice. The *vector of science* is impacted by not only the philosophies applied, but by the subjects, theories, and

[1] Horacio Capel, "The History of Science and the History of the Scientific Disciplines.," Universidad de Barcelona, December 1989, http://www.ub.edu/geocrit/geo84.htm.

methodologies involved. The *vector of science* is the exploration of what the future of science will look like given a particular set of philosophical circumstances.

The *vector of science* contains certain aspects which will assist in conceptualizing the perpetuation of science through time, not as a simple cause and effect, but as a regularly updating directionality of continuation. Vectors have both a magnitude and a direction and, by extension, the vector of science metaphor would also contain elements of magnitude and direction.

The magnitude of the vector of science indicates the energy, prolificacy, and regularity with which science is likely to continue. In other words, how prevalent and relevant are new questions and new experiments being proposed and executed? There could be many reasons for a kind of stalled vector of science or a vector with a low magnitude including philosophical and technological impasses. Science, as shall be shown, has not moved through time with predictable and regularly scheduled discoveries and many thinkers have observed this phenomenon[2]. Thus, the magnitude of the vector of science directly addresses the ebbs and flows, stuttered starts and accelerations, and even the retreating steps of scientific movement through time in a future oriented context. It highlights the prediction that science will continue to resist consistent discovery scheduling moving forward.

Direction in the vector of science refers to the trend toward particular ideas, goals, and pursuits. Two concepts are able to describe the direction of the vector of science. First, the *directional next* refers to actions in the direction of the vector in the immediate future. Second, the *trajectory of science* refers to actions or conclusions in the direction of the vector as an end result. The *directional next* asks which types of questions are being proposed and what possible

[2] Panel on Mathematics (Nonlinear Science and the Navy) et al., *Nonlinear Science* (Washington, D.C.: National Academy Press, 1997).

studies could be pursued in this directional space? The answers to these questions form the concept that will thus be called the *directional next*. The *directional next* is the set of specific inquiries, actions, and behaviors a scientist might follow as a result of a particular work or situation – a set of possible work in the direction of the vector. On the other hand, the *trajectory of science* asks where science will end up? Following the direction of the vector, any conclusions or predicted changes to the vector of science and the path through which these conclusions would be achieved will thus be called the *trajectory of science*. Examples of predicted *trajectories of science* are that science will be defined by a finite set of fundamental laws or that all scientific theories will be reducible to a single theory. These are broad sweeping conclusions to which a particular vector could point. The vector of science does not always provide a clear *directional next* nor does it always imply a specific *trajectory of science*. Instead, these are ways of conceptualizing the direction of the vector of science.

This paper is fundamentally about the impact of scientific disciplines on this perpetuation of science through time. Through this exploration, one may wonder about the singularity of the vector of science. If, as will be the conclusion of this paper, individual disciplines apply philosophical principles distinctly, have different beliefs and expectations surrounding the future of their inquiry, and often work on independent theories and conclusions, there may be room for the application of this vector metaphor on each discipline independently. This concept will be referred to as the vector of a particular discipline (i.e., the vector of chemistry). These vectors of particular disciplines will have their own magnitudes and directions which will indicate the ways those disciplines will continue through time. While it may be useful at times to understand the vector of science as a singular entity, it may be a more robust conclusion to understand the perpetuation of science through time as entirely more disciplinary with multiple vectors impacting one another.

Structures and Assertions

This paper contains two main exploratory sections. First, there is the exploration of what demarcates science from other forms of thought and other practices. Second, there is the exploration of what demarcates different disciplines of science from one another and how those disciplines might be organized. These first two sections involve analyzing the relevant topic according to the subjects studied, the theories postulated, the methods employed, and the interpretation involved: analyzing each in turn. First, this paper explores the subjects of inquiry – from ducks to dark matter to deities. Which thinkers are tasked with the investigation of these subjects? Then, this paper explores the nature of theories – from explanation to connection to application. What questions and postulates direct research and reflect current understanding? Then, this paper explores the methods of inquiry – from dependent variables to derivations to declarations. What are the procedures and rules that distinguish scientific thinkers? Finally, this paper explores the interpretations and disseminations – from journals to journeys to jumbles. What beliefs, benefits, and bargains does metaphysical interpretation dictate?

The conclusions drawn from these explorations on scientific demarcation and on discipline demarcation inform the broader impact disciplines may have on the vector of science and how individual discipline vectors may behave. The conclusion is the investigation of interdisciplinarity in science as it relates to the frameworks previously discussed. Conclusions from the preceding sections inform conclusions about interdisciplinarity and the unique challenges presented by the disciplines on interdisciplinary research. Specifically, it is shown that in the space of academia where much science is conducted there are procedures which can bridge the divides between disciplines including awareness of differences (comparability), acceptance of equality of approaches (parity), and deliberate collaboration on interdisciplinary science (synergy).

Science is a complex, powerful, and diverse practice. Disciplinarity within that practice reflects the complexity of the topic based on the desire to sort and catalogue scientific discovery. Science is often considered the authority on truth and fact. At the very least, it is regularly applied to everyday experiences and life-altering events. Science is revered and respected as an honest mechanism for prediction, explanation, and even comfort. Thus, understanding the ways in which it continues through time and optimizing its disciplinarity has immediate consequences for science itself and society as a larger whole. Beyond the impact of science itself, interdisciplinarity is a popular topic in science today with many universities and scientists advocating for more interdisciplinary work[3][4]. However, there are a number of challenges with interdisciplinarity which derive from the construction and function of disciplines in science[5]. Thus, science, disciplines, and interdisciplinarity are interconnected and impactful ideas for the future of scientific research. This is the main focus of this paper – the understanding of disciplines in scientific work and their impact on the future of science.

Science, as shall be shown, is a somewhat culturally defined practice with many of its ethos tied to, but not defined by, specific behaviors and philosophies. Understanding the function

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[3] Elisabeth Pain, “Multidisciplinary Research: Today's Hottest Buzzword?,” Science, January 3, 2003, https://www.sciencemag.org/careers/2003/01/multidisciplinary-research-todays-hottest-buzzword.

[4] Michelle Appleby, “What Are the Benefits of Interdisciplinary Study?,” OpenLearn (The Open University, March 1, 2019), https://www.open.edu/openlearn/education/what-are-the-benefits-interdisciplinary-study.

[5] Miles MacLeod, “What Makes Interdisciplinarity Difficult? Some Consequences of Domain Specificity in Interdisciplinary Practice,” *Synthese* 195, no. 2 (July 2016): pp. 697-720, https://doi.org/10.1007/s11229-016-1236-4.

of disciplines within a scientific system remains a treacherous task with minimal resolution as disciplines are similarly defined by their social ethos rather than strict philosophical criteria. However, the explorations of both science itself and scientific disciplines are important precursors to understanding the challenges with interdisciplinary research. Interdisciplinary research encounters roadblocks because of the ways that science and scientific disciplines are constructed. Interdisciplinary research, without careful consideration of the philosophical divides, are rarely able to address the differences in disciplines' subjects, theories, methods, and interpretation. To mitigate deep philosophical and metaphysical divides between disciplines in their pursuit of interdisciplinarity, the disciplines might work on their comparability, parity, and synergy. The perpetuation of science through time, the vector of science, is influenced and driven by the philosophy and context of science; each action and belief in science impacts the science that will be done next and on through time. Thus, the operation of disciplines and the measured pursuit of interdisciplinarity has a significant impact on the vector of science providing the context for scientific progression. The conclusions of the fundamental questions of scientific discipline function and interdisciplinary pursuit are mechanisms for the perpetuation of science through time.

Scientific Demarcation

Introduction

This first section focuses on the scientific demarcation problem which traditionally attempts to separate science from pseudoscience; however, a broader scope is applied here. Rather than focusing on the two major criteria of pseudoscience, which, according to Hansson, requires that a practice 1) not be science, and 2) attempt to give the impression that it is science[6], this section only explores the first criteria. In other words, this section explores the distinguishing features between science and non-science. Specifically, what distinguishes scientific subjects from non-scientific subjects, what distinguishes scientific theories from non-scientific theories, what distinguishes scientific methods from non-scientific methods, and what distinguishes scientific interpretation from non-scientific interpretation.

Many thinkers who have explored the demarcation question look for distinguishing criteria that are necessary, in that all science must necessarily follow this criterion, and sufficient, in that no other criteria are needed to properly distinguish science from non-science[7]. However, no consensus on this necessary and sufficient criterion is established. Therefore, a thorough exploration of the relevant thinkers on the subject is necessary to understand what distinguishes science. Sometimes thinkers did not make sweeping statements on what was and was not science; instead, they pondered on the nature of science wherein one might find distinguishing characteristics. These analyses too will be explored as they have implications for the demarcation problem.

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[6] Sven Ove Hansson, “Defining Pseudoscience and Science,” in *Philosophy of Pseudoscience: Reconsidering the Demarcation Problem* (Chicago: University of Chicago Press, 2013).

[7] Martin Mahner, “Demarcating Science from Non-Science,” *General Philosophy of Science*, 2007, pp. 515-575, https://doi.org/10.1016/b978-044451548-3/50011-2.

Understanding what distinguishes science from other practices achieves a couple of goals for determining the structure and function of disciplines in science. First, distinguishing science helps to define the scope of the problem as scientific disciplines generally exist within established scientific practice. Second, discussion of the demarcation problem for science itself provides a framework of philosophies and concepts for the demarcation and understanding of individual disciplines. Overall, distinguishing science from other activities is a tremendously common starting place for many thinkers and will assist in introducing the philosophies with a great impact on the behaviors of science and scientific disciplines.

What makes a scientific subject of study?

If a scientist is setting out to conduct science, what are the subjects of their study? For many approaches to the question of demarcation which will be discussed throughout this paper, science can, in principle, study anything as long as it is studied in a scientific way. This is to say that many interested in this question of scientific demarcation cite criteria based on theoretical, methodological, and interpretation aspects rather than physical ones (each of which will be covered in the next few sections). From a historical rather than philosophical perspective, the scientific community and society as a whole dictated what types of subjects can be studied under the heading of science. For example, religion studies deities and religious texts, and while many philosophers of science made claims about the existence of God, religion is generally categorized outside of the scope of science. Thus, a kind of tautology is formed - science studies whatever scientists choose to study. Science studies trees and quarks as well as ocean waves and heat. This diversity often subverts clear categorization. However, one may attempt to parse and pattern the common elements of these subjects of scientific study in order to perhaps locate a common thread.

Derived from principles expressed by Carnap, for example, one may come to the conclusion that science studies theoretical and observable objects and phenomena. To begin, one can uncontroversially say that science studies objects that are observable. While observable linguistically implies the use of the eyes, the other senses have been employed in scientific study. Carnap described observations as those unaided by technical instruments or inferences[8]. However, because science is a mechanism of explanation rather than just observation, it can be said that science also studies phenomena[9]. For example, science can study humans, an object, and it can study human behavior, a phenomenon. Therefore, it may be concluded that science can study observable objects and phenomena. Observability is thus a candidate for the common link among subjects that science studies; however, with improvements in technology more objects and phenomena can be observed - those that are smaller and further away. While these would not be considered observable according to Carnap, as they require technical instruments to observe, they nonetheless rely, though enhanced, on the five senses to observe. Thus, the criteria may be expanded to include objects and phenomena that are observable either aided or unaided as no one would deny that organelles and distant galaxies, for instance, fall under the jurisdiction of science. Furthermore, some of the subjects that science studies are those which rely almost exclusively on technology to observe requiring specific materials and software to detect. These kinds of technologies do not merely enhance the five senses, instead a scientist is observing a signal from a screen and not the objects themselves. This is so far removed from the idea of direct observation that Carnap described as these observations require both instruments and

[8] Rudolf Carnap, "Theories and Nonobservables," in *Philosophical Foundations of Physics* (Basic Books Inc., 1966).

[9] National Academies of Sciences, "Scientific Methods and Knowledge," in *Reproducibility and Replicability in Science* (Washington, D.C: National Academies Press, 2019).

interpretation. Carnap viewed such detections as theoretical rather than observational. For example, one may observe that the liquid in a thermometer rises, but the phenomenon of temperature change is theoretical[10]. Following this line of thinking, electrons and electromagnetic waves which cannot be directly observed, only detected, are technically theoretical. Once again, not many would deny that these theoretical objects and phenomena still fall under the jurisdiction of science. Therefore, the subjects of scientific inquiry, using this language, are observable and theoretical objects as well as observable and theoretical phenomena.

This criterion is so broad as to be not particularly compelling. For instance, one may claim that divine intervention, a traditionally religious and not scientific subject of study, is a theoretical phenomenon. Upon adding increasingly abstract subjects to the scientific repertoire and distancing these subjects from the five senses, there is not complete consensus on which and how certain scientific subjects exist. Thus, this may be a necessary but not sufficient criteria for scientific demarcation. Nonetheless, this exploration and categorization of scientific subjects has significant implications for discipline demarcation and interdisciplinarity. While there are not necessary and sufficient criteria nor much discussion for distinguishing science on the basis of subjects, there is quite a bit of discourse in other areas wherein interesting truths about science may be revealed. The next section will explore the distinguishing of science based on the theories it employs.

[10] Rudolf Carnap, "Theories and Nonobservables," in *Philosophical Foundations of Physics* (Basic Books Inc., 1966).

What makes a scientific theory?

If a scientist is setting out to conduct science, what do their theories look like? To understand the context of the discussion surrounding the demarcation of science based on theories, one should discuss some of the major historical proposals for this kind of demarcation. With each approach to this question, the definition of theory stretches and morphs. The concept of a theory as a possible explanation for phenomena, anomalies, and observations has taken different names and had has been defined by different fundamental properties. Thus, during this discussion the definition of a scientific theory will adapt and its definitional formation is a kind of demarcation itself. It is true that many of these attempts to demarcate science remain impactful to the ethos and behavior of science today even if the proposals are not widely accepted anymore.

The Logical Positivist in the early 20th century tried to standardize scientific behavior and in doing so proposed a theoretical demarcation on the basis of verificationism[11]. This is the principle that a scientific theory is one that can be verified using a finite set of observations. This was considered a criterion for meaning and subsequently undermined itself[12]. However, the principles of collecting empirical data to support a scientific theory has lived on beyond the logical positivists[13]. This model, proposed by the Vienna Circle, suggested that theories are useful tools as long as they are grounded in observations which support them, but theories alone are not enough to be considered science.

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[11] Samir Okasha, "Verificationism, Realism and Scepticism," *Erkenntnis* 55, no. 3 (2001): pp. 371-385.

[12] Jonathan Surovell, "Carnap's Response to the Charge That Verificationism Is Self-Undermining," PhilSci Archive, March 14, 2013, http://philsci-archive.pitt.edu/9629/.

[13] Jonathan Surovell, "Carnap's Response to the Charge That Verificationism Is Self-Undermining," PhilSci Archive, March 14, 2013, http://philsci-archive.pitt.edu/9629/.

Popper is arguably one of the most influential philosophers who distinguished science purely by theoretical demarcation. He was reacting to principles of verificationism and to research he believed to be pseudoscientific occurring at the time. Popper believed the only sufficient and necessary criteria needed to determine science from non-science is that of falsification. A particular theory was scientific if and only if it was testable and refutable[14]. Popper compared Einstein's theory of gravitation with other new theories being tested at the time including Freudian Psychology. Instead of confirming his theory by multitudes of positive evidence surrounding him, as Freud did, Einstein waited to make a prediction which was testable and could prove his theory wrong. Thus, according to Popper, Einstein's theory is falsifiable and testable, and therefore constituted science rather than non-science. Popper was criticized a number of times for various inconsistencies with his criterion including the belief that falsification as a strict theoretical concept has itself been falsified[15]. The practice of falsification has more often been applied to the formation of hypotheses rather than all-encompassing theories. As a part of scientific behavior, almost all scientists with an experimental view of science require a testable, falsifiable hypothesis. Thus, falsification lives on in scientific practice.

Kuhn was another thinker who changed the way science viewed itself and postulated theories. His historical analysis of science led to different conclusions on what constitutes a scientific theory. For Kuhn, a paradigm was a broad scientific theory that was not directly falsifiable in most everyday science (Kuhn's normal science)[16]. Instead of following the

[14] Karl Raimund Popper, *The Logic of Scientific Discovery* (Vienna: Logik der Forschung , 1935).

[15] Nicholas Maxwell, "A Critique of Popper's Views on Scientific Method," *Philosophy of Science* 39, no. 2 (1972): pp. 131-152, https://doi.org/10.1086/288429.

[16] Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Chicago, IL: The University of Chicago Press, 1962).

Popperian ideal of perfectly formulated scientific theories, Kuhn suggested that new paradigms were accepted and rejected based on a number of guiding principles and that the ultimate decision was left up to the scientific community. The principles that the scientific community uses in times of revolution reflect the values of that community. Some of the principles that are possible priorities, according to Kuhn, are accuracy with data, internal and external consistency, broad scope, explanatory power, simplicity, and providing a clear and impactful next step[17]. Thus, a Kuhnian criteria for a scientific theory is one which the scientific community accepts based on the priorities they set. This is far less prescriptive than Popper's criteria as well as being historically rather than philosophically defined.

While most of the examples in Kuhn's book were from physics and chemistry, Kuhnian ideas were readily adopted by many fields, especially social science. Fields like sociology, economics, and political science could meet requirements for being sciences[18]. Theories, according to Kuhn, did not need to follow any particular criteria, but had to instead be adopted by the discipline's community. Thus, theories in these broader disciplines which couldn't meet stringent verification or falsification criteria could behave in a Kuhnian manner and be considered scientific. Science became a broader category of behaviors and disciplines. Of course, this was not the first time that these disciplines could be considered science; however, it was an important distinction for the development of modern scientific consideration. It's important to note that behaving in a Kuhnian manner is not a necessary or sufficient criterion for science, but

[17] Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Chicago, IL: The University of Chicago Press, 1962).

[18] W. Keith Percival, "The Applicability of Kuhn's Paradigms to the Social Sciences," *The American Sociologist* 14, no. 1 (February 1979): pp. 28-31.

a framework to understand scientific behavior. Instead, Kuhn demarcated science by the conclusions of the scientific community[19].

After Kuhn published his book, others utilized the methods of historical analysis to formulate their own ideas about scientific inquiry. Specifically, Lakatos and Laudan responded to Kuhn's ideas. Lakatos believed method and falsifiability still had major roles to play in the shifting of scientific paradigms which he called research programs. Research programs had a scientific theory or concept, known as the core which was the central theory of the research program with smaller falsifiable theories which, in some ways, insulate the core from falsification[20]. These outer theories and beliefs are known as the positive heuristics; they work within the research program and follow much more traditional and empirical views of scientific theorizing and methodology. This structure proposed a blending of criteria in scientific practice; thus, if a practice deviated too far from this theoretical structure it would be considered less scientific. Theoretical procedure and principle, in the Lakatosian view, still mattered in the conception and perpetuation of science. In other words, the vector of science would not be left solely to the scientific community.

When it comes to postulating scientific theories, it follows that a scientist's view on the goal of science will impact the types of theories they propose. These goal-driven implications on theories of science are not reaching for the necessary and sufficient criteria for which that demarcation question often searches; however, they impact the theory-based behavior of science and are worth exploring further. Specifically, there has been some debate on whether the goal of

[19] Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Chicago, IL: The University of Chicago Press, 1962).

[20] Imre Lakatos, *The Methodology of Scientific Research Programmes Philosophical Papers*, ed. John Worrall and Gregory Currie (Cambridge: Cambridge University Press, 1978).

science is to create a complete picture of knowledge, or to solve problems and create applications[21]. A more pragmatic goal would postulate far more applicable theories while a more general goal would postulate theories relating to the gaps in the whole picture of the field. Agreeing on the goal of science would likely create theories of a more uniform nature, but would, as a demarcation criterion, likely exclude very important historical and future scientific work.

Ziman along with other thinkers proposed a method of knowledge production which shifted the traditional goal of science in exactly this way. Specifically, the Mode-2 knowledge production, as it is known, focuses on industrial rather than academic science and is primarily focused on application[22][23]. From a goal perspective, this is a framework for science with a more pragmatic goal. This theory is somewhat at odds with the normative beliefs of academic science and highlights the differences in scientific practice based on the fundamental goals of that science.

Those criteria about theories which are philosophically rather than historically defined such as verificationism and falsifiability are not wholly accurate and applicable throughout scientific history for what is widely considered science[24][25]. In order to avoid excluding these theories, these core principles and proposals could be considered normative statements. For

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[21] Aboutorab Yaghmaie, “How to Characterise Pure and Applied Science,” *International Studies in the Philosophy of Science* 31, no. 2 (March 2017): pp. 133-149, https://doi.org/10.1080/02698595.2018.1424763.

[22] Michael Gibbons et al., *The New Production of Knowledge the Dynamics of Science and Research in Contemporary Societies* (Los Angeles, CA: Sage, 1994).

[23] J. Ziman, *Real Science: What It Is and What It Means* (Cambridge: Cambridge University Press, 2002).

[24] Jonathan Surovell, “Carnap's Response to the Charge That Verificationism Is Self-Undermining,” PhilSci Archive, March 14, 2013, http://philsci-archive.pitt.edu/9629/.

[25] Nicholas Maxwell, “A Critique of Popper's Views on Scientific Method,” *Philosophy of Science* 39, no. 2 (1972): pp. 131-152, https://doi.org/10.1086/288429.

example, instead of saying that those theories which are not falsifiable are not science, one may say that scientific theories should try to be falsifiable. Science, in modern practice, often takes these proposed criteria as normative statements and folds them into the goals and practices of science in order to be accepted and established within the scientific community. These statements and expectations also provide a descriptive framework to understand what scientific theories tend to look like.

Scientific theories are not usually observed in isolation, however. Instead, these theories are deeply connected with the methods that certain belief systems performed. The next section will explore how thinkers have distinguished scientific methodologies from other procedures.

What makes a scientific method?

If a scientist sets out to conduct science, what methodological beliefs and practical methods do they utilize? Methodology and strategies employed by scientists in order to think about problems, collect data, and analyze data are far-ranging and powerful tools of demarcation.

Throughout history, science and knowledge have been closely linked. Therefore, some of the demarcation criteria this section will explore will be tied directly to the question of what knowledge is and how it is achieved. This practice is called epistemology. It is therefore appropriate to wonder if the demarcation of science from other activities is the pursuit of absolute truth rather than an approximation, model, or other asymptotical conception of truth. Many thinkers conflated science with knowledge and therefore proposed an equivalency between the methodological strategies for distinguishing science with the methodological strategies for distinguishing knowledge, especially when those methods are philosophically rather than historically defined[26]. For much of history science, as a practice, was somewhat indistinguishable from philosophy. Thus, inklings of scientific demarcation can be found within the philosophical debates surrounding knowledge and epistemology.

An example of such an epistemic debate was that of rationalism and empiricism. The central epistemic conflict of this debate was whether people come to know the world through logic and thought, rationalism, or if people know the world through sense and experience, empiricism[27].

Some of the most famous rationalists were Descartes, Spinoza, and Leibniz. Descartes utilized what he called the method of doubt in order to understand what is true about the world. He came to the conclusion that what is true is that which is “clearly and distinctly perceived”[28]. While there is some debate on interpreting these criteria, the conclusion by Descartes is fairly clear - the only truths that are fully clear and distinct are those derived from intellection and reasoning[29]. In other words, he excluded all imagination and sense perception from being fully clear and distinct and therefore from being certain. Thus, for the purposes of distinguishing science from other activities, his philosophy might be analyzed as the doubting of sense experience, the reliability of reason, and an emphasis on mathematics. Utilizing his ideas of true and certain facts he developed geometric proofs and even the cartesian coordinate system still in

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[26] Carl J Wenning, “Scientific Epistemology: How Scientists Know What They Know,” *Journal of Physics Teacher Education Online* 5, no. 2 (2009): pp. 3-15.

[27] Peter Markie, “Rationalism vs. Empiricism,” Stanford Encyclopedia of Philosophy (Stanford University, July 6, 2017), https://plato.stanford.edu/entries/rationalism-empiricism/.

[28] “Descartes' Meditations on First Philosophy,” Descartes' Meditations on First Philosophy, n.d., https://www.csus.edu/indiv/g/gaskilld/intro/epistemology2webnotes.htm.

[29] Elliot Samuel Paul, “Cartesian Clarity,” *Philosophers' Imprint* 20, no. 19 (2020): pp. 1-28.

use today[30]. Rationalists, like Descartes, believed that knowledge was gained only through reason and logic and not through experience therefore science, if science is equivalent to knowledge, was not the practice of collecting sense data, but of reaching rational conclusions.

The rationalist view of truth and certainty contrasted the views of the empiricists and specifically, the empirical view of epistemology. Again, for the purposes of scientific demarcation, the epistemological approach is highlighted. Some of the most famous empiricists were Locke, Berkeley, and Hume. Locke believed that all knowledge is derived from experience[31]. Berkley argued that all qualities ascribed to objects exist only in perception[32]. Both these thinkers believed that all knowledge was derived from the perceptions or those qualities associated with the five senses; however, these perceptions did not necessarily reflect objective reality. This tradition of empiricism, known as British Empiricism, thought that one can only have knowledge of their own perceptions and not of the outside world itself [33]. Thus, the inaccessibility of physical knowledge about the world implies an inaccessibility of science to say anything about reality. Therefore, science practiced through observation, would describe not what is, but only what is perceived.

A kind of culmination of these discussions lives with the logical empiricists sometimes called the logical positivists. The differences between these labels reflect the diversity of thinkers within the broader movement. Logical empiricists rejected many rationalist beliefs because, as

[30] Lanetta Burdette, "Rene Descartes," Wichita State University Math, n.d., https://www.math.wichita.edu/history/men/descartes.html.

[31] Robert Nichols, "Empiricism of John Locke," Acumen Digital Magazine (Lehigh University, n.d.), https://acumen.cas.lehigh.edu/content/empiricism-john-locke.

[32] Barry Stroud, "Berkeley v. Locke on Primary Qualities," *Philosophy* 55, no. 212 (April 1980): pp. 149-166.

[33] Barry Stroud, "Berkeley v. Locke on Primary Qualities," *Philosophy* 55, no. 212 (April 1980): pp. 149-166.

the name implies, they were empiricists who believed that knowledge was only accessible through sense experience; however, their position differed slightly from that of the British empiricists. Sense experience, to the logical empiricists, could say something about objective reality or was the closest that science could get to the truth[34]. As previously mentioned, the logical positivists generally believed in verificationism requiring that all knowledge be confirmed by the senses, though not all logical empiricists shared this particular view. Mathematical conceptualizing, amoung most logical emiricists, would act as a tool to aid direct observation and does not provide any truth of its own[35]. As much as logical empiricism was a philosophical movement, it was also a cultural one with individual thinkers meeting in groups and institutes to discuss their ideas and concerns about scientific methodology. Thus, their views were fairly diverse and debated. Additionally, the movement channeled many of their beliefs into influencing scientific methodology at the time. This influence reflected their core beliefs of observation as the primary method of scientific behavior. Their success in influencing scientific methodology is reflected in their continued relevancy to modern science.

These discussions so far have dealt with the broad, general methodological principles drawn from epistemic debates; however, practical considerations and direct procedures are equally important to scientific methodology. For this exploration, one cannot deny the impact of Bacon. Bacon proposed the scientific method most widely acknowledged today[36]. While he has had his critics, his clear criteria for scientific methodology cannot be ignored. Bacon believed

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[34] Richard Creath, "Logical Empiricism," Stanford Encyclopedia of Philosophy (Stanford University, April 5, 2017), https://plato.stanford.edu/entries/logical-empiricism/.

[35] Richard Creath, "Logical Empiricism," Stanford Encyclopedia of Philosophy (Stanford University, April 5, 2017), https://plato.stanford.edu/entries/logical-empiricism/.

[36] Florian Cajori, "The Baconian Method of Scientific Research," *The Scientific Monthly* 20, no. 1 (1925): pp. 85-91.

that science was systematic, organized, and relied on inductive reasoning. He rejected the entrenched Aristotelian views and proposed his new method for science. He is credited with influencing the European scientific revolution which would include the works of Newton. Bacon's scientific method has maintained tremendous influence over the scientific community and scientific practice including introducing the procedure of the modern scientific experiment[37]. A truly methodological demarcation of science would insist upon a method that is systematic and doubts previous entrenchment. These criteria as well as the use of specific procedures is the demarcation criteria that Bacon proposed[38]. Further thinkers as well as scientists, in the course of their work, have developed and refined the types of scientific procedures that are accepted, especially with technological advances. However, Bacon's principles remain at the forefront of all these standardized procedures.

Throughout all these debates, most thinkers believed that science was defined by and demarcated by its methodology; the most prevailing belief was that method determined whether a person was conducting science or simply thinking about a subject. As was previously stated, many believed that science could study any subject as long as a scientific methodology was utilized - this is methodological demarcation. Kuhn and the historical thinkers that followed him did a lot, however, to minimize the importance of strict methodology in scientific practice by pointing to specific historical examples. No thinker was as controversial and central to the minimizing of method as Feyerabend. He wrote a book entitled *Against Method*[39]. He utilized historical arguments to indicate that no standard method would capture all the relevant and

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[37] Florian Cajori, "The Baconian Method of Scientific Research," *The Scientific Monthly* 20, no. 1 (1925): pp. 85-91.

[38] Florian Cajori, "The Baconian Method of Scientific Research," *The Scientific Monthly* 20, no. 1 (1925): pp. 85-91.

[39] Paul Feyerabend, *Against Method* (New Left Books, 1975).

important scientific discoveries of the past. He had a kind of radically individualistic view of science taking Galileo as his strongest historical example. Feyerabend's premise was that all the methodological beliefs and criteria could not have led to Galileo's laws of motion. These laws did not fit with other theories at the time, Galileo's theory did not provide particularly more explanatory power than established theories, and Galileo's theory contained anomalies with the data. Therefore, using almost every methodology conceivable it was simply irrational for Galileo to adopt this theory; however, Galileo changed science significantly and was, according to Feyerabend and many today, a great scientist. As a result, Feyerabend did not believe in a strict scientific method which could be applied to all science[40]. Thus, according to Feyerabend, science could not be defined by its methods.

The final view of scientific method comes from sociology rather than philosophy or history. Specifically, Merton proposed a theory which numbers specific tenets that science attempts to live up to in order to be accepted as part of a social view of science – universalism. communality, disinterestedness, and organized skepticism. Two of the tenets have implications for scientific method. Merton believed that science should have disinterestedness. Disinterestedness is the principle of doing science without bias and for the sake of science itself rather than to serve some personal goal. Merton also believed that science should engage in organized skepticism which is the principle that all science is subject to scrutiny. This scrutiny can come in the form of peer review, logical skepticism, or reproducibility[41]. As an organized social group, scientists hold each other accountable under greater scrutiny than other activities.

[40] Paul Feyerabend, *Against Method* (New Left Books, 1975).

[41] Robert K Merton, "Science and the Social Order and The Normative Structure of Science," in *The Sociology of Science: Theoretical and Empirical Investigations* (Chicago, IL: The University of Chicago Press, 1973), pp. 254-278.

These principles are, according to Merton, what distinguishes scientific methodology from other activities. Merton's norms for scientific behavior drew their own reactions especially when thinking about science not as an epistemological practice but as a practical one[42]. However, Merton's norms still have relevancy among the historical philosophical principles and their implementation in modern science.

Scientific demarcation based on methodology remains one of the most popular and accepted demarcation criteria. A central question that arises from the discussion of demarcation based on method is whether science is chasing absolute truth, whether science is approaching and approximating absolute truth, or whether science is unable to make direct claims about absolute truth[43]. The answer to this question is not particularly easy to determine despite the enormous impact such an answer would have on the vector of science. Following broad principles or specific procedures cannot conclusively claim to be conduits to this elusive absolute truth. Claims about the objective truth of scientific inquiry are an example of scientific interpretation. In addition to reviewing the subjects, theories, and methods of science, it is important to explore the uniqueness of scientific interpretation. This is what the next section will cover.

What makes a scientific interpretation?

When it comes to scientific interpretation, the line between interpreting current science and theorizing for future science is often blurred. In fact, many thinkers have debated the question of whether science begins with observation and data collection then makes theoretical

[42] J. Ziman, *Real Science: What It Is and What It Means* (Cambridge: Cambridge University Press, 2002).

[43] Carl J Wenning, "Scientific Epistemology: How Scientists Know What They Know," *Journal of Physics Teacher Education Online* 5, no. 2 (2009): pp. 3-15.

conclusions from those observations, or if science begins with a theory which is then supported by observation and data collection[44]. These are, of course, oversimplifications of historical behavior in science. However, they reveal the central question in the exploration of scientific interpretation as separate from scientific theorizing and has many implications for scientific demarcation. Though, interpretation discussions generally do not attempt to find necessary and sufficient criteria for the distinguishing of science as interpretation generally follows after the traditional procedure of science. However, when viewed as a step in the larger scientific process and viewed with its close ties to future theories, one may see the distinguishing characteristics. In other words, interpretation is the mechanism of the perpetuation of science through time – an important component of the vector of science. Instead of viewing science as isolated studies and experiments, one can view a more holistic scientific procedure which involves interpretation as an essential step, regardless of whether it simply appears as theorizing for the next experiment or involves more complex behaviors.

Logical positivism, as a philosophy, was deeply concerned with the removal of metaphysics from science. The principles of verificationism, when it is said to cover meaningfulness, suggest that questions of value, meaning, and unobservable phenomena, not only are excluded from scientific behavior, but are themselves meaningless[45]. However, logical positivism and logical empiricism belong to a social movement with many different thinkers. The members of the Vienna Circle, for instance, disagreed often about many big questions. However, they mostly agreed on the tenant of removing metaphysics from the practice of

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[44] "Philosophy of Science," University of Oregon Lectures, n.d., http://abyss.uoregon.edu/~js/21st_century_science/lectures/lec01.html.

[45] Samir Okasha, "Verificationism, Realism and Scepticism," *Erkenntnis* 55, no. 3 (2001): pp. 371-385.

science[46]. Under this model, scientific interpretation would not include metaphysical questions. By trusting the epistemological significance of the scientific method, these thinkers did not view interpretation, especially metaphysical interpretation, as a priority in scientific thought. To the logical empiricists, science began with theories as tools for guiding empirical scientific practice and, through this procedure, the results would largely speak for themselves[47].

While Popper's early works on falsification advocated that the necessary and sufficient criteria for science was that scientific theories were falsifiable, he also provided some interesting insight into what makes an interpretation scientific. Specifically, he advocated that scientists, when faced with falsifying data, must abandon their theories. Popper was not the only one who advocated for the acceptance of evidence as a distinguishing criterion; however, he provided good examples on how acceptance of results might be difficult or counterintuitive in certain practices, especially those he viewed as unscientific[48]. Specifically, he criticized Marxists for constantly changing their theory to accommodate what Popper saw as falsifying data. True scientists, according to Popper, engaged in interpretation which accepted falsifying results as refutation of their theory and attempted to postulate a new falsifiable theory to test. Others criticized this view based on a number of points[49]; however, the value of acceptance of results remains central to scientific ethos and practice[50]. Like the logical empiricists, if narrow, specific,

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[46] Friedrich Stadler, *The Vienna Circle: Studies in the Origins, Development, and Influence of Logical Empiricism* (Cham: Springer, 2015).

[47] Richard Creath, "Logical Empiricism," Stanford Encyclopedia of Philosophy (Stanford University, April 5, 2017), https://plato.stanford.edu/entries/logical-empiricism/.

[48] Karl Raimund Popper, *The Logic of Scientific Discovery* (Vienna: Logik der Forschung , 1935).

[49] Nicholas Maxwell, "A Critique of Popper's Views on Scientific Method," *Philosophy of Science* 39, no. 2 (1972): pp. 131-152, https://doi.org/10.1086/288429.

[50] Howard Wolinsky, "Paths to Acceptance," *EMBO Reports* 9, no. 5 (2008): pp. 416-418, https://doi.org/10.1038/embor.2008.65.

and often mathematical theories were used, interpretation beyond confirming or disproving the theories was not necessary. Popper's contribution to this conversation was the necessity of scientists to accept scientific results and abandon falsified theories. Thus, the demarcation criteria proposed was that science, unlike non-science, accepted evidence as interpretation.

In both these contexts, continuation of method – question to data to next question – is the way in which science is perpetuated through time. The direction of research is largely linear in a progression from less knowledge to more knowledge. Thus, the trajectory of science progresses closer to some conclusionary truth. The magnitude of the vector according to this viewpoint is affected more by individual action and proximity to the conclusionary truths than by larger systemic changes in the scientific canon.

However, viewing interpretation as synonymous with new theory assumes that evidence is objective, truthful, and indisputable. While logical empiricists believed in scientific objectivity, their critics explored the theory-ladenness of observation - the concept that observation, data, and evidence are influenced by the theory under which they are conducted. Certain arguments about theory-ladenness were influenced or proposed due to the findings and writings of Gestalt psychologists. Gestalt psychologists were exploring the nature and fallibility of human observation. They reported that top-down influences of beliefs, expectations, and knowledge can change one's view of the same physical experience. In psychology, this is the widely accepted concept of the separation between sensation and perception. Fallacies and mistakes in observation, it must be noted, can be overcome with awareness, effort, and repeated exposure to induce what is known as a Gestalt shift - the ability to suddenly perceive previously missed stimuli and subsequently the ability to switch between one's original perception and the shifted perception[51]. These ideas of top-down or mental influences on perceptual experience were applied to scientific observation. Therefore, the modern view of theory-laden observation was born. Science is not necessarily unique in the ladenness of observation and interpretation in comparison with other human endeavors; however, philosophy of science, especially that of the logical empiricists, prized objectivity which may be rebutted by theory-ladenness[52]. Scientific observation alone may not be as objective as many believed nor would it be equivalent to interpretation. Instead of simply accepting the reality of results, theory-ladenness implies the necessity of unpacking the theory-laden observations through interpretation[53].

Kuhn, when exploring his ideas of scientific revolution, introduced the concept of incommensurability. Incommensurability is the idea that across paradigms there is no common measure, and the two paradigms cannot be directly compared as a result[54]. Kuhn wrote about incommensurability throughout his life reacting to criticism and commentary. These sections reflect mostly his early musings on the subject of incommensurability. Kuhn was a proponent of the theory-ladenness of observation. Theory-ladenness of observation is referred to as observational incommensurability. Reasonable individuals from different paradigms could look at the same object or phenomenon and come to different conclusions while still behaving in a

[51] Julian E. Hochberg, “Gestalt Theory and It's Legacy,” in *Perception and Cognition at Century's End* (Amsterdam etc.: Elsevier, 2007).

[52] C. A. Hooker, “Empiricism, Perception and Conceptual Change,” *Canadian Journal of Philosophy* 3, no. 1 (1973): pp. 59-75, https://doi.org/10.1080/00455091.1973.10716070.

[53] Norwood Russell Hanson, *Patterns of Discovery: an Inquiry into the Conceptual Foundations of Science* (Cambridge England: Cambridge University Press, 2010).

[54] Paul Hoyningen-Huene, “Kuhn's Conception of Incommensurability,” *Studies In History and Philosophy of Science Part A* 21, no. 3 (September 1990): pp. 481-492, https://doi.org/10.1016/0039-3681(90)90006-T.

rational and scientific manner[55]. Thus, each scientist is engaging in interpretation of results rather than completely removing interpretation from scientific behavior – interpreting identical observations within their own paradigm.

Additionally, Kuhn defined a methodological incommensurability which depended on the standards on which one judges normal science within a paradigm. Normal science, according to Kuhn, is the puzzle-solving science conducted within a paradigm which attempts to solve conceptual anomalies with the prevailing theory[56]. The interpretation of normal science and the specific anomalies it attempts to solve are different in each paradigm. In other words, the prevailing paradigm sets the standard through which normal science will be carried out. For example, action at a distance versus mechanistic action was a paradigm shift in physics. In the newer paradigm which allowed action at a distance, normal science did not spend time finding a mechanism of explanation for particular phenomena whereas this was a consistent source of anomalies in the mechanistic paradigm[57]. As previously discussed, the scientific community, according to Kuhn, chooses new paradigms based on certain values. There are many reasons why one paradigm is chosen over another, and these reflect the values of the scientific community. The standards of the winning paradigm are usually based on the values to which that theory holds. Thus, in this example, the action at a distance paradigm valued fitting to data and more often worked on anomalies where data were inconsistent while the mechanistic paradigm valued

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[55] Paul Hoyningen-Huene, “Kuhn's Conception of Incommensurability,” *Studies In History and Philosophy of Science Part A* 21, no. 3 (September 1990): pp. 481-492, https://doi.org/10.1016/0039-3681(90)90006-T.

[56] Paul Hoyningen-Huene, “Kuhn's Conception of Incommensurability,” *Studies In History and Philosophy of Science Part A* 21, no. 3 (September 1990): pp. 481-492, https://doi.org/10.1016/0039-3681(90)90006-T.

[57] J.V. Narlikar, “Action at a Distance and Cosmology: A Historical Perspective,” *Annual Review of Astronomy and Astrophysics* 41, no. 1 (2003): pp. 169-189, https://doi.org/10.1146/annurev.astro.41.112202.151716.

explanatory power and thus focused on anomalies where there was no mechanistic explanation. The behaviors of normal science in each paradigm were not being measured on the same standards and thus, there is no metric for their direct comparison. This is Kuhn's methodological incommensurability[58]. Once again, one can see the role of interpretation in science on a longer timeline which includes paradigm shifts and their different interpretations. According to Kuhn, scientific interpretation, much like scientific theory, is left up to the values and beliefs of the scientific community.

Finally, Kuhn took issue with the logical empiricists attempts to put scientific work into a neutral, objective language. Such language did not, in Kuhn's view, exist. He defined a semantic incommensurability as a failure of translation between the language and lexicon of one paradigm and that of a competing paradigm. The definitions were different between these different paradigms, but even more broadly this meant that the interconnected words and concepts they described carried different meanings between different paradigms. Kuhn used the example of the paradigm shift between Newtonian mechanics and relativity. In each paradigm, the definitions of words such as space, time, and mass were completely different and therefore statements of theory utilizing these words would have different meanings[59]. Furthermore, the interconnectedness of words and theory mean that simple translation between the theories is extremely difficult and translation to a language unconnected with any theory is impossible. Scientific interpretation is therefore somewhat incomparable across paradigms unless careful

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[58] Paul Hoyningen-Huene, "Kuhn's Conception of Incommensurability," *Studies In History and Philosophy of Science Part A* 21, no. 3 (September 1990): pp. 481-492, https://doi.org/10.1016/0039-3681(90)90006-T.

[59] Paul Hoyningen-Huene, "Kuhn's Conception of Incommensurability," *Studies In History and Philosophy of Science Part A* 21, no. 3 (September 1990): pp. 481-492, https://doi.org/10.1016/0039-3681(90)90006-T.

consideration is paid to the semantic incommensurability. The process of ardent and challenging translation between paradigms suggests that interpretation requires acknowledgement of the larger paradigm in which science is working.

Each of these types of incommensurability has faced its own criticisms and corrections[60]. However, Kuhn's incommensurability challenges the view of a trajectory of science that approaches greater truth and builds upon itself. Scientific interpretation, in a Kuhnian model, does not simply build upon previous scientific results, but builds within the paradigm. Scientific interpretation, therefore, differs from paradigm to paradigm and no necessary and sufficient criteria can be established for all of science.

Lakatos, in his response to Kuhn, added a new consideration for scientific interpretation. In a Lakatosian research program, interpretation is not just about how the new results fit into the prevailing research program, but also how they contribute to the status of the research program itself. Specifically, new results could be evidence of degeneration or progression of the research program itself and point to new anomalies within the research program[61].

Both Kuhn and Lakatos did not distinguish science from non-science with interpretation but highlighted the challenges with viewing observation and interpretation as equivalent. In this view, interpretation is an important step in the procedure of science and can determine whether a prevailing theory is accepted or rejected.

In the context of the vector of science, Kuhn left the vector of science up to the scientific community where they would choose between a directional next of further puzzle-solving or of

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[60] Alexander Bird, "Kuhn's Wrong Turning," *Studies in History and Philosophy of Science Part A* 33, no. 3 (2002): pp. 443-463, https://doi.org/10.1016/s0039-3681(02)00028-6.

[61] Imre Lakatos, *The Methodology of Scientific Research Programmes Philosophical Papers*, ed. John Worrall and Gregory Currie (Cambridge: Cambridge University Press, 1978).

scientific revolution[62]. The broader idea is that the trajectory of science is that of revolution rather that a strict progression from less knowledge to more knowledge. Lakatos introduces two important ideas for the vector of science - progression and degeneration. A progressive research program suggests a vector of science with active and interesting directional nexts involving solving the anomalies in the program, while a degenerating research program suggests a vector of science without a directional next or with only a small set of following questions[63]. Thus, this directly conceptualizes the notion of magnitude. However, it is important to note that some research programs can progress while other degenerate in parallel; thus, this Lakatosian conception of a vector's magnitude applies to the vectors of individual research programs rather than to the vector of science as a whole. Post-Kuhnian philosophy of science proposes a trajectory of science which is strictly non-linear; science reaches conclusions in shifts and reevaluations.

Finally, Merton's sociological view of science and scientific practice has components which affect the notion of scientific interpretation. First, his principle of universalism, which is closely related to the logical empiricist view of objectivity, suggests that claims made in science must be held to consistent and impersonal criteria[64]. Interpretations must meet particular criteria of objectiveness before being accepted as science. However, this expectation is less related to the removal of metaphysics and more associated with the removal of personal and political biases. Second, his principle of communality which suggests that science should be commonly available

[62] Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Chicago, IL: The University of Chicago Press, 1962).

[63] Imre Lakatos, *The Methodology of Scientific Research Programmes Philosophical Papers*, ed. John Worrall and Gregory Currie (Cambridge: Cambridge University Press, 1978).

[64] Robert K Merton, "Science and the Social Order and The Normative Structure of Science," in *The Sociology of Science: Theoretical and Empirical Investigations* (Chicago, IL: The University of Chicago Press, 1973), pp. 254-278.

among the scientific community in a kind of common property. Interpretations and conclusions must be shared amongst other members of the scientific community. This communality would leave results open to greater scrutiny and alternative interpretations for which scientists must be prepared[65].

A sociological view of scientific practice generally reflects the ethos and goals of scientific consideration rather than philosophical certainty. Once again, one can note that even criteria that one might philosophically reject often becomes part of the scientific ethos. Merton, in many ways, makes normative the philosophical principles of other thinkers, as previously discussed. Instead of attempting to define what science is philosophically and logically, these principles suggest what science should be in order to be socially accepted. Thus, Merton's analysis and other sociological views suggest that, once again, acceptable scientific interpretation is that which is acceptable within the community of science and within its social rules.

Overall, the demarcation of science is not often approached from the perspective of scientific interpretation; however, in different philosophical models one can see that there are different approaches to the act of scientific interpretation. One may uniquely identify these interpretations in scientific practice regardless of whether a necessary and sufficient criterion is reached. Scientific interpretation is a unique mechanism for understanding the vector of science and thus, must be considered from various perspectives.

Conclusion

The conclusion that is reached through this discussion is that thinkers in science and philosophy of science do not agree on necessary and sufficient criteria to demarcate science from

[65] Robert K Merton, "Science and the Social Order and The Normative Structure of Science," in *The Sociology of Science: Theoretical and Empirical Investigations* (Chicago, IL: The University of Chicago Press, 1973), pp. 254-278.

other activities. Moreover, there is growing evidence that such criteria cannot exist when viewing past scientific behavior. This conclusion has profound effects on the vector of science through beliefs, behaviors, and values. A strict criterion, for instance, might provide explicit details for what comes next in science and where science is meant to go, but as individual philosophies which have an influence on the ethos of scientific behavior, they imply those unique beliefs upon the vector of science. Thus, this question of what science is by definition, principle, or lack thereof impacts what science will get done, how science will get done, and eventually how science will be perceived and applied regardless of the conclusion.

Demarcating science from other behaviors is only one step in determining the function of disciplines in science. How different disciplines interact with and embody the various philosophical concepts discussed is essential to distinguishing them from one another and establishing their function in the overall concept of science. The language, approaches, and frameworks through which one explores science within a larger system of pursuits and behaviors are the very same as those one can use to explore how disciplines function within a scientific system. Regardless of how ill-defined the practice of science is, the approaches are still important to the question of the function of disciplines in science. The next section will explore this concept and the many ways in which disciplines are distinct from one another.

Discipline Demarcation

Introduction

After exploring what distinguishes science, one is left with many questions regarding the influence of disciplines on these concepts and, inversely, the influence of these concepts on disciplines. Disciplines appear, on the surface, very different from one another because each has its own rich history and philosophical practices. Often disciplines study different subjects, postulate unique theories, employ distinct methods, and interpret their work differently. Even when they hold to congruent tenets, the disciplines reflect these tenets uniquely. Also, as previously discussed, no specific tenets or criteria are universally held in science. Thus, one is left to wonder if the apparent difference between disciplines is merely superficial, a reflection of the lack of a scientific criteria consensus, or an indication of deeper philosophical divides.

A thorough exploration of the demarcation of disciplines from one another is central to understanding the function of disciplines, the nature of science, and the vector of science. Learning from the debates surrounding demarcating science from other activities, it is unlikely that there will emerge any necessary and sufficient criterion that distinguishes say physics from chemistry, thus, this paper will simply explore the philosophical differences without imposing strict demarcative criteria. There is also good reason to avoid creating definitions of disciplines as this would create an unhelpful, narrowing, view on the disciplines and their practices. Some examples of disciplines used throughout this paper are those of physics, chemistry, biology, and psychology; however, exploration will utilize other, more controversial, examples as well.

For instance, it is important, at this point, to recognize the increasing specialization of scientific fields. This has many consequences in the understanding of science and its disciplines. One result of increased specialization is the development of subdisciplines and hybrid disciplines. Take, for example, the field of physics. Instead of viewing physics as its own distinctive discipline, it may be more appropriate to view its subdisciplines and hybrid disciplines separately. In physics, there are subfields such as nuclear physics, material science, and quantum mechanics as well as hybrid disciplines such as biophysics and geophysics. In the exploration of what demarcates different disciplines from one another, one may find that subdisciplines and hybrid disciplines encounter the same demarcation challenges as the broader disciplines.

Finally, there is a common practice to utilize philosophical and demarcation principles to group and organize disciplines. The grouping of certain disciplines reflects certain traits and behaviors which link these disciplines and inversely, separating disciplines reflect distinctions in their traits and behaviors. Furthermore, there has been much history surrounding the creation of hierarchies, webs, and other organization systems which may indicate or assume a particular philosophy. Thus, in addition to demarcating disciplines from one another, this section will indicate ways in which the philosophical, social, and historical practices of certain disciplines have placed them in certain groups and at certain locations in the organization of disciplines.

With the broad principles of demarcation and organization laid out, one may proceed with the examination. Similar to the question of scientific demarcation, this exploration will utilize the categories of subjects, theories, methods, and interpretation. First, this section will explore the demarcation and organization of disciplines based on the subjects that each discipline studies. Second, this section will explore the demarcation and organization of disciplines based on the theories that each discipline postulates. Third, this section will explore the demarcation and organization of disciplines based on the methods that each discipline employs. Finally, this section will explore the demarcation and organization of disciplines based on the interpretations that each discipline accepts. Each of these questions will be studied in turn, of course, utilizing the principles of the previous exploration of demarcating science.

What subjects do disciplines study?

While, as previously discussed, there are not many thinkers who distinguish science from other forms of thought by the subjects being studied, most disciplines are traditionally demarcated this way. In other words, science studies anything while individual disciplines study specific subjects. In fact, it is easy to see this as the essential component of discipline demarcation. Biology is the study of living things. Psychology is the study of behavior and mental processes. Chemistry is the study of the transformations of matter. However, these are almost definitional. Once again, one sees the same kind of tautology - scientific disciplines study whatever that subject was defined to study. This, however, does not provide any particular insight into the true distinctions between the disciplines. Additionally, because science is always changing and moving, the boundaries of the definitional criteria are often tested. Some disciplines share subjects, some subjects are not easily categorized into the disciplines, and these subjects may not account for some major differences between disciplines. One may see that under the seemingly simple demarcation based on the subjects of study, there are complications which are worth exploring.

One might use the categories previously parsed based on Carnap's view of observation, to come to the conclusion that disciplines differ and are organized by the level of abstraction of their definitional subjects of study[66]. The theory described four categories - observable objects, theoretical objects, observable phenomena, and theoretical phenomena. This theory is based on

[66] Rudolf Carnap, "Theories and Nonobservables," in *Philosophical Foundations of Physics* (Basic Books Inc., 1966).

the separation of particular types of detection from direct observation with the five senses[67]. In other words, the labels of observable and theoretical as well as objects and phenomena describe the level and type of abstraction through which a particular subject is detected. Theoretical subjects are separated from direct observation by inference and phenomenal subjects are separated from direct observation by connection. For example, the theoretical object of an electron cannot be directly observed by the five senses one must instead utilize and interpret technology designed to detect the presence of electrons. Thus, one makes a theoretical inference. Additionally, the phenomena of movement may be observed by the five senses but only after the connection of more than one observation of position is observed. It must be noted that much of this concept of abstraction is human-centric as the five senses are subject to human sensory limitations, thus defining how theoretical an object or phenomenon is, not by what it is, but by a human's ability to observe it.

Disciplines study subjects of differing degrees of abstraction from direct observation which may help to describe the definitional differences. Take, for example, the disciplines of psychology and human biology; both of these disciplines study the observable object of human beings. However, psychology is defined as studying behavior and mental processes[68] which are not observable objects at all but rather phenomena. To almost certainly oversimplify, behavior is an observable phenomenon while mental processes are theoretical phenomena. Thus, subdisciplines, like behaviorism, in psychology as well as human biology may be distinguished by their level of and type of abstraction from direct observation. Of course, human biology also

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[67] Rudolf Carnap, "Theories and Nonobservables," in *Philosophical Foundations of Physics* (Basic Books Inc., 1966).

[68] "Psychology," Merriam-Webster (Merriam-Webster, n.d.), https://www.merriam-webster.com/dictionary/psychology.

studies phenomena such as hair growth or blood movement, but human biology definitionally studies the subject of humans, objects, while psychology definitionally studies the subject of human behavior and mental processes, phenomena. Thus, psychology, in comparison with human biology, is a more abstract field, when abstract is defined as the distance from direct observation with the five senses. All this is not a completely unique observation and similar theories have been historically proposed; however, this particular conception of discipline demarcation and organization is derived from the framework previously established in this paper. Thus, the definition of abstraction here is particularly specific.

In order to understand how this proposal organizes the disciplines it may be useful to imagine a sliding scale of the abstraction of each discipline's primary subjects of study despite the original labels of theoretical, observable, objects, and phenomena being discrete. One axis would describe the level of abstraction based on inference or how theoretical a subject is, and the other axis would describe the level of abstraction based on connection or how physical a subject is. Utilizing this scale, one may, as one example of the organization of disciplines by their subjects of study, organize the disciplines from least abstract definitional subjects to most abstract definitional subjects.

Another organization system based on subjects is that of the physical hierarchy in which each discipline's subjects of study are viewed as constituent parts of the subjects of the discipline next on the hierarchy - such that, chemistry underlies biology which underlies psychology which underlies sociology. Society, a subject of sociology, is made up of humans, a subject of psychology. Humans are made up of organs and cells, subjects of biology, and organs and cells are made up of elements and compounds, subjects of chemistry[69]. This is simplified and not particularly definitional in order to emphasize the point of constituency. This is based on merely the observable objects that disciplines study. This organization system is closely related to the organization system proposed by Comte who viewed the subjects of scientific study as becoming more complex and less generalizable as one traversed a hierarchy from mathematics to sociology[70].

The questions of the subjects of study are further complicated among disciplines when viewed through the lens of fundamental questions. Take for example, the question of "what is life?" This question, most would view, is a question for biology. Biology, in answering this question, would need to understand and study not only life and living things, but non-living things as well in order to draw the distinction. Thus, it is too narrow to distinguish biology as the study of living things. Comparative understanding of scientific practice resists simple distinctions based on subjects of study. In this conception, each subject is studied by many different disciplines making these subjects poor criteria for demarcating disciplines. Illustratively, if one observed a scientist studying a rock, one could not determine whether that scientist was a biologist, geologist, physicist, or chemist unless they knew more information about the questions being asked.

Thus, it can be seen that subjects of study are perceived as the simplest and most intuitive way to demarcate disciplines from one another; however, the lines often get blurred. It is necessary, then, to discuss the other ways in which one might distinguish and organize

[69] Randall C O'Reilly, "Physical Reductionism," Physical Reductionism, April 28, 2017, http://psych.colorado.edu/~oreilly/cecn/node9.html.

[70] V K Maheshwari , "Auguste Comte- Hierarchy of the Sciences," n.d., http://www.vkmaheshwari.com/WP/?p=1603.

disciplines and their scientific behavior. The next section will explore the ways in which the theories postulated by disciplines may distinguish, categorize, or organize those disciplines.

What theories do disciplines postulate?

Through each of the proposed and explored concepts of demarcating science from other forms of thought and practices according to scientific theories, one may explore how they would impact scientific disciplines differently. As established, most of the strict proposals that are largely rejected today were instead taken as normative goals for science to attempt to live up to. Thus, one may ask how well different disciplines do at achieving the ideals of proposed demarcation criteria. Furthermore, one can see the ways in which proposed criteria have impacted the ethos and behavioral practices of science as a whole so it would be likely that each discipline will have a unique history with these criteria. It can be interesting to utilize facets of these criteria in order to distinguish disciplines from one another, explore the development of subdisciplines, and categorize and organize the scientific disciplines. This section will explore the proposed demarcation criteria based on scientific theories as they relate to distinct disciplines.

Logical Positivism was as much a movement and a coalition as it was a philosophy. There were many thinkers who considered themselves positivists. Specific to the demarcation and organization of the sciences, Comte proposed a hierarchy which reflected the speed of a particular discipline toward positivism in intellectual history. In Comte's hierarchy disciplines lower on the hierarchy such as Astronomy and Physics moved quickly away from theology and metaphysics toward positivist theorizing while disciplines higher on the hierarchy such as Sociology moved more slowly away from these less positivist theoretical conceptions. Comte believed that eventually Sociology would follow the same path as Astronomy towards a verificationist ideal[71]. In this framework, disciplines are organized and demarcated by the development of the discipline and its theories through time.

Popper, in his views on falsification, proposed a kind of continuum of more scientific theories to less scientific theories through the concept of making risky predictions. According to Popper, theories with greater risk and greater willingness to be proven incorrect are more scientific, and theories with lots of self-corrections are less scientific[72]. This indicates that rather than strict demarcation between science and non-science, the theories exist on a sliding scale. It follows that one could use Popperian principles to organize the disciplines from the most scientific to the least scientific based on the types of theories those disciplines usually propose and how risky those theories are. However, there is no definitional component to indicate the types of theories a particular discipline will propose. Instead, this scale would likely indicate not something fundamental about the disciplines, but instead the amount of influence Popper's proposals have on the practices of each discipline. Once again, this is the normative interpretation of falsification.

Another form or hierarchical organization specific to the conversation of discipline demarcation and organization, is that produced by theory reductionism. Theoretical underpinning, similar to the physical underpinning previously described, is the basis for the construction of this type of hierarchy. A hierarchy which places the disciplines with the most fundamental laws, those to which other laws can be reduced, at the most foundational position[73].

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[71] V K Maheshwari , "Auguste Comte- Hierarchy of the Sciences," n.d., http://www.vkmaheshwari.com/WP/?p=1603.

[72] Karl Raimund Popper, *The Logic of Scientific Discovery* (Vienna: Logik der Forschung , 1935).

[73] Sahotra Sarkar, "Models of Reduction and Categories of Reductionism," *Synthese* 91, no. 3 (1992): pp. 167-194, https://doi.org/10.1007/bf00413566.

Anderson argues against this form of reductionism, though not necessarily against this organization, on the basis that theories from disciplines further from the most fundamental position cannot be formulated by the further study of the more fundamental discipline. In other words, less fundamental theories are reducible to but not derivable from more fundamental theories[74]. Regardless of the directionality of the connection between the theories, there remains a fundamental enforcement of the hierarchy itself. If the theories exist on a hierarchy, the disciplines which postulate these theories would therefore exist on the same hierarchy. This creates an organization of the disciplines which looks remarkably familiar with physics occupying the most fundamental rung of the hierarchy and social sciences occupying the least fundamental rungs. However, Anderson's conclusion about the inability of more fundamental theories to derive the less fundamental theories is remarkable in its indications for discipline independence. If one cannot derive a chemical theory from a physical theory, as Anderson argues, then chemistry is at the very least theoretically independent of physics[75]. This indicates greater divides between disciplines and the necessity of their unique perspective.

Next, it is interesting to consider the Kuhnian concepts and proposals as they relate to the relationship between disciplines. For instance, different disciplines behave differently during times of scientific revolution[76]. It was previously discussed that the choices made in scientific revolution reflect the values of the scientific community that makes the choice. Viewing each

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[74] Philip W. Anderson, "More Is Different," *Science* 177, no. 4047 (August 4, 1972): pp. 393-396.

[75] Philip W. Anderson, "More Is Different," *Science* 177, no. 4047 (August 4, 1972): pp. 393-396.

[76] Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Chicago, IL: The University of Chicago Press, 1962).

discipline as a separate scientific community one can see the differences in their priorities and values in times of revolution.

Biology and other life sciences often prioritize explanatory power over predictive power while physics and other physical sciences often prioritize predictive power over explanatory power[77]. Thus, each of these disciplines value each of these properties to a greater degree. As a result, if a theory in life science is able to explain a previously unexplained question of why, it is more likely to be selected in these fields during revolutions. A good example of a prevailing theory which had significant explanatory power is that of evolution. Evolution and natural selection could explain not what traits a species had, but why a species had those traits indicative of a high degree of explanatory power. However, in physical sciences such as physics and chemistry predictive power is far more prioritized in the selection of a prevailing theory. Evolution does not often attempt to predict future states of species; however, Newtonian mechanics, a prevailing theory in physics, was and remains extremely predictive of the objects it describes. These disciplines are distinct in the components of a good scientific theory that they prioritize as a discipline-specific community and therefore, theories in one discipline are remarkably distinct from theories in other disciplines.

While Kuhn's work did a lot to expand the disciplines considered to be scientific, when it came to theories, it implied that there could be only one accepted paradigm (prevailing theory) at a given time in a given discipline. However, this does not account for the specialization nor the diversity of particular disciplines. While physics, for instance, has maintained a fairly consistent paradigm which attempts to explain all of the phenomena in the scope of the discipline, other

[77] John Timmer, "Scientists on Science: Explanatory Power and Predictions," Ars Technica, September 16, 2006, https://arstechnica.com/shttps://arstechnica.com/science/2006/09/5315/cience/2006/09/5315/.

disciplines might have several concurrent paradigms. This is why Lakatos's interpretation has more power and may be more appropriate in certain fields with high diversity and specialization - Lakatos allowed for more than one research program in a given field.

Disciplines are distinct from one another in their number of prevailing theories (paradigms, research programs) at a given time. Some disciplines are structured with many concurrent prevailing theories which work mostly independently while others follow a more traditional Kuhnian model with one main theory which is explored by small puzzle-solving hypotheses. One could then organize the disciplines based on their theoretical diversity by grouping disciplines with high numbers of research programs and disciplines with low numbers of research programs. This, of course, could be deeply influenced by the scope of the disciplines and the homogeneity of its subject matter.

Perhaps instead, it is best to consider concurrent prevailing theories as independent subdisciplines. Since a given field cannot, according to interpretation of Kuhn, contain more than one paradigm, perhaps concurrent paradigms are indicative of distinct disciplines. Each of Lakatos's research programs would then be considered its own discipline[78][79]. Similar to Popper, perhaps the colloquial disciplines, as people currently sort them, are more socially defined than philosophically consistent. As a result, disciplines and subdisciplines could be better conceptualized and demarcated by their theories even if the general sensibilities and university departments suggest a lack of independence.

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[78] Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Chicago, IL: The University of Chicago Press, 1962).

[79] Imre Lakatos, *The Methodology of Scientific Research Programmes Philosophical Papers*, ed. John Worrall and Gregory Currie (Cambridge: Cambridge University Press, 1978).

After having discussed the concept of goal-based influence on scientific theories, one is left to wonder on how this distinguishes different disciplines from one another. For instance, the goals of medicine and pharmacology are far more practical than those of biology, chemistry, or biochemistry. It follows that these more pragmatic disciplines would postulate far more applicable theories about pathology for instance while the more general disciplines would postulate theories relating to the gaps in the whole picture of the field. These different goals and theory behaviors are unique even when disciplines study very similar subjects. Just as the goals of science distinguish it from other behaviors and endeavors, the goals of different disciplines distinguish their theories from theories proposed by other disciplines.

Ziman modeled his theory of industrial science on Merton's scientific norms and thus included a list of normative goals toward which science would strive. These criteria are very different than the community and carefully allocated goals in Merton's theory. These criteria represent the main functions of industrial science. Ziman specifically described a list of industrial, application-based ethos for science of this variety to uphold. Ziman suggested that "industrial science is Proprietary, Local, Authoritarian, Commissioned, and Expert"[80]. Proprietary refers to the lack of sharing of proprietary scientific discovery. Local refers to the smaller technical problems that science is called upon to solve. Authoritarian refers to the non-individualistic managerial system under which science is conducted. Commissioned refers to the direct practical problems that science is asked to solve. Finally, Expert refers to the view of scientists as expert problem solvers rather than skeptical and curious[81].

[80] J. Ziman, *Real Science: What It Is and What It Means* (Cambridge: Cambridge University Press, 2002).
[81] J. Ziman, *Real Science: What It Is and What It Means* (Cambridge: Cambridge University Press, 2002).

It is unlikely that all sciences are particularly apt for a shift from academic to industrial scientific practice – from Merton's norms to Ziman's norms, from general to practical – thus certain disciplines will be able to live up to the Ziman's norms better than others. One can view the disciplines with pragmatic goals not as applied sciences but as industrial sciences and those disciplines with a more general goal as academic sciences according to this model.

In this exploration of what makes discipline theories distinct, one wonders further about the ways in which disciplines and subdisciplines develop and are categorized. Discipline-specific theory behavior is one way in which these disciplines might be understood to be distinct; however, methods and interpretation may also provide insight into this question of discipline demarcation.

What methods do disciplines use?

It has been seen that, while maybe not strictly demarcated, disciplines and even subdisciplines are distinct in accordance with their subjects of study and theories. It follows that the continued exploration of discipline demarcation and organization as it relates to the methods employed and the connections with forms of scientific demarcation is likely to yield interesting discipline distinctions. Thus, this section will analyze the different methodological beliefs of individual disciplines.

First, the rationalism and empiricism debate has a lot to suggest about each discipline's connection with truth and epistemology. Rationalism applied to modern science would only include disciplines like theoretical physics, which do not rely on sense experience or data collection, as truth[82]. Take, for example, Einstein's theory of relativity, while it can be said that

[82] Peter Markie, "Rationalism vs. Empiricism," Stanford Encyclopedia of Philosophy (Stanford University, July 6, 2017), https://plato.stanford.edu/entries/rationalism-empiricism/.

Einstein was studying the phenomena of time, he was not measuring it directly or even secondarily[83]. It was not until the experimental evidence of relativity was revealed that any variables were observed or measured at all and these measures were carried out by arguably a different subdiscipline of physics[84]. Because modern science does not uphold a purely rationalist viewpoint, relativity was not fully accepted until empirical data was gathered. Thus, theoretical physics may be considered an epistemologically significant activity by the rationalists. The rationalists' belief in truth being derived from rational thought and mathematics would exclude most scientific disciplines, including those that provided the empirical evidence of relativity, as achieving truth[85]. In other words, disciplines that are not purely theoretical or mathematical in nature would not be considered objective truth by the rationalist. These disciplines, in the rationalist view, allow one to perhaps approximate knowledge but not to know absolutely.

Empiricists applied to modern science would, of course, reject the rationalist notion that mathematical or theoretical sciences reflect objective truth. However, while empiricists, in their purest sense, did believe that knowledge is derived from perception, they did not believe that those perceptions could access objective reality[86]. Thus, observation-based scientific disciplines, too, may also be excluded from empiricists' view of knowledge. British empiricism, specifically, creates an epistemological trap which makes most physical knowledge completely inaccessible. However, especially as the logical empiricists took empirical views and made them more

[83] Daniele Sasso, "Short History of Relativity," *Manifesto of Contemporary Physics*, November 2013.

[84] Daniele Sasso, "Short History of Relativity," *Manifesto of Contemporary Physics*, November 2013.

[85] Peter Markie, "Rationalism vs. Empiricism," Stanford Encyclopedia of Philosophy (Stanford University, July 6, 2017), https://plato.stanford.edu/entries/rationalism-empiricism/.

[86] Peter Markie, "Rationalism vs. Empiricism," Stanford Encyclopedia of Philosophy (Stanford University, July 6, 2017), https://plato.stanford.edu/entries/rationalism-empiricism/.

practical for scientific application, empiricism has ultimately had a significant impact on most disciplines in science aside from purely theoretical disciplines[87]. Most disciplines require careful observation rather than pure rationalism. The logical positivists or logical empiricists would likely view theoretical physics as a tool to support experimental physics. It follows that, in this view, theoretical physics would not be considered its own scientific discipline as it is not grounded in empirical data. Interestingly, this is the first time a criterion has suggested the combination rather than the distinction of two disciplines. The philosophy of logical empiricism suggests that theory and experimentation cannot be easily separated and made into distinct subdisciplines as the debate so far may have one believe.

Once again, the broad methodological principles definitely have an impact on scientific disciplinarity; however, the more implementable and explicit methods and procedures of science must also be analyzed. Thus, the next methodological distinction that may apply differently to individual disciplines is that of experimental methods versus descriptive methods[88]. Both of these methods are a systematic collection of information; however, they each have unique methodologies and logical conclusions. The next few paragraphs will compare between controlled experimentation and classification utilizing examples of each method from both chemistry and biology. This exploration can shine a light on the ways in which different disciplines interact with scientific method.

It has been discussed that Popper's falsifiability is more applicable to hypotheses rather than broad scientific theories, such as, those controlled experiments with refutable hypotheses

[87] Richard Creath, "Logical Empiricism," Stanford Encyclopedia of Philosophy (Stanford University, April 5, 2017), https://plato.stanford.edu/entries/logical-empiricism/.

[88] Upen, "Difference Between Descriptive and Experimental Research," Pediaa, June 21, 2018, https://pediaa.com/difference-between-descriptive-and-experimental-research/.

that live up more closely to the falsifiability ideal. The methodology of a controlled experiment with variable manipulation is attributed to Bacon[89]. Interestingly, these methods have been used across multiple traditional disciplines. Examples from biology and chemistry will help highlight the ways in which experimentation is used across disciplines. These examples, in particular, are illustrative due to their simplicity. Specifically, Pasteur's experiment with boiled broth would contribute to the disproving of spontaneous generation in biology[90] and Boyle's experiment with the elastic properties of air would describe a chemical law for which he was the eponym[91]. Both of these experiments, though existing in different disciplines, relied upon creation of apparatus, the controlling of specific variables, and the logic of causation. For Pasteur, contact with the open air caused the formation of microbes in the broth. For Boyle, a change in the volume of air caused a change in the pressure. Without experimentation, this form of causal logic is widely seen as unacceptable.

Similar to the understanding of experimental methods, descriptive methods can be explored using examples from biology and chemistry. Many disciplines employ the use of classification, a descriptive method, in order to categorize observable subjects in their field. Classification and taxonomy are the practices of organizing and categorizing a set of things according to particular criteria[92]. Classification takes many different forms - some systems observe and document subjects as they are found, some perform experiments to determine

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[89] Florian Cajori, "The Baconian Method of Scientific Research," *The Scientific Monthly* 20, no. 1 (1925): pp. 85-91.

[90] "Louis Pasteur 's Experiment," San Diego Miramar College, n.d., http://faculty.sdmiramar.edu/dtrubovitz/micro/history/Pasteur.html.

[91] "Robert Boyle," Purdue University, n.d., http://chemed.chem.purdue.edu/genchem/history/boyle.html#:~:text=Boyle's.

[92] Daniel Parrochia, "Classification," Internet Encyclopedia of Philosophy, n.d., https://iep.utm.edu/classifi/.

theoretical properties. Classification can be viewed as pragmatic rather than truly fundamental as multiple organizations of the same subjects are accepted as scientifically valid[93]. This is distinct from the conclusions of experimentation. Disciplines employ and understand classification in different ways.

Thus, in exploring two historical examples of classification, one may observe the relationship between classification methods and scientific disciplines. The first example is biological taxonomy which is a very old and storied form of classification. Many systems for categorizing living things were proposed through this history each based on different criteria which were observable at the time. The widely accepted system is that of Linnaeus which categorized living things based on certain observable criteria, specifically those he viewed as naturally occurring[94]. Interestingly, the staying power of this classification system is largely due to its consistency with evolutionary theory which was proposed later[95]. The second example is elemental organization which has a similar history to biological taxonomy in that it is a system based on similar features which held up to a later developed theory. Mendeleev, who developed the widely accepted periodic table of elements used today, did not know about the structural similarities that would later be proposed[96] (specifically, the connection between atomic weight and atomic number). Instead, he utilized the known chemical properties of the discovered

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[93] Daniel Parrochia, "Classification," Internet Encyclopedia of Philosophy, n.d., https://iep.utm.edu/classifi/#:~:text=.f

[94] "Carl Linnaeus," University of California at Berkeley, https://ucmp.berkeley.edu/history/linnaeus.html.

[95] Arthur Cronquist, "On the Relationship Between Taxonomy and Evolution," *Taxon* 18, no. 2 (April 1969): pp. 177-187, https://doi.org/10.2307/1218675.

[96] "Chemistry - Chapter 2 - Atoms and Periodic Table," Western Oregon University, n.d., https://wou.edu/chemistry/courses/online-chemistry-textbooks/ch150-preparatory-chemistry/ch150-chapter-2-atoms-periodic-trends/.

elements to observe and organize consistent patterns. These examples are very similar in their use of classification techniques despite existing in different disciplines.

Experimental and descriptive methods, as outlined here, are used in many of the traditionally defined disciplines, like biology and chemistry. However, once again, it may be interesting to consider how these methods may categorize subdisciplines each with methods that distinguish them. This form of categorization between experimental and descriptive sciences may be useful, despite that chemistry and biology have each been shown to both employ both methods. There are some distinctive differences one can observe about these methods and their effect on the vector of science. Individual experiments, as one may observe with Pasteur and Boyle, generally have a much smaller scope than classification systems. Additionally, classification, as one may observe with Linnaeus and Mendeleev, does not, in its original methodology, claim causal reasoning. Finally, experiments rely more heavily on methodological replicability while classification relies more heavily on repeated observations[97]. Each of these impacts the vector of their disciplines. Thus, the subdisciplines of chemistry and the subdisciplines of biology, in this case, which employ these distinct methods may be considered separately due to their different methods and scopes.

Minimizing method, as the post-Kuhnians, especially Feyerabend, did, allowed for a more generous view of scientific disciplines. Thus far this paper has mostly avoided discussing the political and institutional definitions of science and scientific disciplines which will be explored later on; however, it is important to mention that Feyerabend, in his advocacy for the elimination of dogmatic methodology[98], was also advocating freedom from the narrow views and

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[97] Upen, "Difference Between Descriptive and Experimental Research,"
[98] Paul Feyerabend, *Against Method* (New Left Books, 1975).

traditions of establishment science. This is essential to his argument, as it allowed for disciplines without institutional backing, perhaps those previously labeled as pseudoscience such as alternative medicines, to be considered with a scientific lens[99]. Feyerabend was radically unconcerned with restricting scientific thought believing that scientific heroes would emerge to indicate the disciplines that provided the best path forward for knowledge and understanding. In this way, the minimizing of method also minimized the distinctions between disciplines. Disciplines, in Feyerabend's conception, existed on a level playing field and each was equally likely to produce an important breakthrough.

Finally, Merton's theories on the sociological norms of science exclude very few scientific disciplines from consideration as science[100]. However, for these norms to operate a community or social group of scientists must exist. Especially for organized scrutiny, peer review and reproducibility, a community which understands the technical, as well as the philosophical components of the produced science is required. It follows that the smaller this peer group the less skeptical power they would have. Therefore, with increased specialization and the creation of more subdisciplines, these smaller, more niche disciplines would be less able to conduct organized scrutiny. This, once again, suggests that the subdisciplines, so readily created based on theory-based criteria, do not have the sociological establishment to be separated so easily on the basis of method.

Disciplines behave differently in their methods and behaviors. Each is distinct in their interpretation of and compliance with different methodological criteria. Additionally, logical

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[99] Paul Feyerabend, *Against Method* (New Left Books, 1975).

[100] Robert K Merton, "Science and the Social Order and The Normative Structure of Science," in *The Sociology of Science: Theoretical and Empirical Investigations* (Chicago, IL: The University of Chicago Press, 1973), pp. 254-278.

empiricist ethos and sociological pressures temper the increased specialization of disciplines and suggest that broader, more established disciplines maintain their methodological similarities better than smaller, newer disciplines. The next section will explore how disciplines engage with different scientific interpretations and interpretive philosophies.

What interpretations do disciplines accept?

Scientific interpretation, as was previously shown, is an intricate part of the perpetuation of science through time. The philosophies which indicate particular ways to interpret science are unsurprisingly essential to the analysis of individual disciplines and their vectors.

The logical positivist attempt to remove metaphysical questions of value, meaning, and unobservable phenomena affects disciplines differently. As usual, logical positivism or logical empiricism prioritizes physics as a discipline where theories are generally mathematical and logical in nature rather than descriptive. This movement prided itself on objectivity, neutrality, and universality[101]. These principles, along with Popper's conviction that science must accept empirical evidence, suggests that scientific interpretation is mostly unnecessary, and science is approaching truth with each new theory[102]. One might organize the disciplines, therefore, by where on the journey to objective truth they are in comparison with other disciplines. This is yet another way to interpret Comte's organization of the sciences. Comte viewed the sciences as progressing through intellectual history away from metaphysical belief toward truth and each of the sciences had a different pace on this progression. The truth of astronomy, for example, would

[101] Richard Creath, "Logical Empiricism," Stanford Encyclopedia of Philosophy (Stanford University, April 5, 2017), https://plato.stanford.edu/entries/logical-empiricism/.

[102] Karl Raimund Popper, *The Logic of Scientific Discovery* (Vienna: Logik der Forschung , 1935).

be known earlier than the truth of, say, biology[103]. This can be viewed as an interpretive hierarchy of disciplines and indicative of a vector of science with a very specific trajectory of science.

The concept of theory-ladenness of observation, with its roots in psychology, implies that it is the fault of the humanness of scientists[104]. Humans are fallible in their observations and therefore lack strict objectivity. Thus, it is simple to conclude that technology is a resource to combat theory-ladenness of observation[105]. If one can remove the sensory component of scientific observation one can curtail the impact of theory-ladenness. From this conclusion, disciplines which rely more on detection devices than human observation would need to be less concerned about theory-ladenness of observation. One could distinguish and group scientific disciplines based upon their reliance on fallible human observation. However, there is some evidence to suggest that technology does not eliminate theory-ladenness of observation. As previously discussed, detection devices require a theoretical leap in interpreting data as unobservable objects are, as Carnap concluded, theoretical[106]. For example, a device that detects electrons relies on the theoretical construct of electrons existing and behaving in a particular manner. Thus, at least some of the top-down influences that lead to theory-ladenness remain present.

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[103] V K Maheshwari , “Auguste Comte- Hierarchy of the Sciences,” n.d., http://www.vkmaheshwari.com/WP/?p=1603.

[104] Julian E. Hochberg, “Gestalt Theory and It's Legacy,” in *Perception and Cognition at Century's End* (Amsterdam etc.: Elsevier, 2007).

[105] Nicola Mößner, “Photographic Evidence and the Problem of Theory-Ladenness,” *Journal for General Philosophy of Science* 44, no. 1 (March 2013): pp. 111-125, https://doi.org/10.1007/s10838-013-9219-3.

[106] Rudolf Carnap, “Theories and Nonobservables,” in *Philosophical Foundations of Physics* (Basic Books Inc., 1966).

It is interesting to consider Kuhnian concepts and proposals as they relate to the relationships between disciplines and not just the relationships between paradigms[107]. When using theories to demarcate disciplines, one can view any concurrent paradigms within an established discipline as a separate subdiscipline. These subdisciplines may have overlapping subjects of study or consider similar questions. Thus, applying Kuhn's notions of incommensurability to disciplines and especially subdisciplines can provide a lot of insight. If paradigms are incommensurable, one is left to wonder if disciplines, with their distinct paradigms, are incommensurable as well[108].

Theory-ladenness, though previously discussed, is a Kuhnian type of incommensurability known as observational incommensurability[109]. If disciplines, like paradigms, cannot agree on the facts of observation due to their theories, then cross-disciplinary work would be extremely difficult. With paradigms, two competing paradigms may observe the same data or observation and interpret it in two different ways. Similarly, subdisciplines within a larger discipline are more likely to observe the same data or observation and may do so in two different ways because of their different prevailing theories.

In addition to observational incommensurability, Kuhn defined methodological incommensurability which may additionally be applied to disciplines in the same way it is

[107] Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Chicago, IL: The University of Chicago Press, 1962).

[108] Paul Hoyningen-Huene, "Kuhn's Conception of Incommensurability," *Studies In History and Philosophy of Science Part A* 21, no. 3 (September 1990): pp. 481-492, https://doi.org/10.1016/0039-3681(90)90006-T.

[109] Paul Hoyningen-Huene, "Kuhn's Conception of Incommensurability," *Studies In History and Philosophy of Science Part A* 21, no. 3 (September 1990): pp. 481-492, https://doi.org/10.1016/0039-3681(90)90006-T.

applied to paradigms[110]. This form of incommensurability gives voice to the distinctions previously outlined such as those in relation to subjects, theories, and methods. In fact, viewing it this way gives possible reasons for the different behaviors across disciplines since prevailing paradigms set the standards by which normal science, in a Kuhnian sense, is done. Thus, if the values of a particular discipline align most with particular philosophies, then the standards of behavior accepted and expected within the discipline will follow those philosophical expectations. For instance, since physics has never been traditionally excluded from any scientific philosophy, physics is able to maintain values that are somewhat unobtainable for other disciplines such as risky falsifiability. However, as sociological views demonstrate, these principles are more often applied in the way of expectation rather than strict criteria. Thus, normal science in physics may have the greater expectation of falsifiability compared with other disciplines. If the differing standards, expectations, and values between disciplines previously explored are viewed through this Kuhnian incommensurability framework, one may observe that different disciplines, like different paradigms, are somewhat incomparable in their conclusions.

The third and final type of incommensurability that Kuhn discussed was semantic incommensurability. The lexicon of disciplines is significantly diverse and often have very few overlapping terms. However, semantic incommensurability implies the necessity of speaking the language, as it were, of a prevailing theory in order to understand the interpretation of science in that theory. Along this line, disciplines and subdisciplines demarcated by their single prevailing theory would utilize different language and semantic structures in their interpretation, and translation across these disciplines would require careful consideration of semantic

[110] Paul Hoyningen-Huene, “Kuhn's Conception of Incommensurability,” *Studies In History and Philosophy of Science Part A* 21, no. 3 (September 1990): pp. 481-492, https://doi.org/10.1016/0039-3681(90)90006-T.

incommensurability. Additionally, the implication of the lack of a universal neutral language into which science can be translated is that individual disciplines are more disconnected from one another in their interpretation than in, say, their methodology. In other words, two studies could be conducted using almost identical procedures, but have semantic incommensurability in their interpretive conclusions.

It may be necessary, at this time, to recall that interpretation is a mechanism for the vector of science and for the perpetuation of science through time. The conclusion that one can come to with regard to disciplinary vectors of science is that individual disciplines require their own independent conception of the vector of science which may look different than the overall vector of science. Within this viewpoint, it is likely that the directional next of a vector of science would be far more general than the exact experiment or study of an individual discipline's directional next. Furthermore, a particular discipline, like physics, may have a trajectory, like fundamental laws describing all phenomena, while other disciplines, like biology, may not have a trajectory at all. It can also be seen, through the action of individuals flocking toward particular disciplines, which disciplines are the most prolific and therefore have the greatest magnitude. As previously introduced, the concept of the vector of science is hardly singular as it cannot imply any clear implementable directional next nor be particularly useful in describing the future of scientific research. Instead, one may find great success in considering each discipline to have a independent vector of science with an individual interpretation of its work.

Finally, Merton's sociological view of science has implications for disciplines in their interpretation[111]. Specifically, one can see how individual disciplines live up to the ideals of universalism and communality. Universalism, as a disconnect from politics, can act as a reminder that the political and monetary systems through which science is conducted must be taken into account in the interpretation of science. Sciences, in modern practice, are funded through organizations which rely on the traditional, broad disciplines of science with the expectation that the values of those disciplines will be applied to the science. One might, because of this monetary structure and a belief in universalism, see scientific disciplines as demarcated by their means of funding or by their university department. Universalism is the unpacking of the political influences in interpretation to reach closer to that objective, impersonal ideal. Merton's next interpretive criteria for science additionally has implications for the demarcation and organization of disciplines. Merton believed in the ideal of communality or the free sharing of scientific interpretation. Interestingly, the reality of communality or a lack thereof is much more complicated. This system usually requires money and connection to access most scientific results from prestigious journals. Additionally, these requirements are impacted by the views of journals and the predominant disciplines published in those journals[112]. These usually maintain some connection with the traditional, broad disciplines. Once again, one can see that the traditional views of disciplines cannot be so readily separated from the behavior of science especially when political systems are taken into account. It is important to note, however, that Merton's view

[111] Robert K Merton, "Science and the Social Order and The Normative Structure of Science," in *The Sociology of Science: Theoretical and Empirical Investigations* (Chicago, IL: The University of Chicago Press, 1973), pp. 254-278.

[112] Alexander Kaufmann and Andrea Kasztler, "Differences in Publication and Dissemination Practices between Disciplinary and Transdisciplinary Science and the Consequences for Research Evaluation," *Science and Public Policy* 36, no. 3 (January 2009): pp. 215-227, https://doi.org/10.3152/030234209x427121.

apply mostly to academic science and thus greater understanding of these cultural systems and different approaches to scientific practice is necessary.

Understanding the ways in which disciplines interpret their work, especially ideas like incommensurability, directly ties into the vector of disciplines and the nature of interdisciplinary work. However, analysis of Merton's sociological view in accordance with disciplines indicates the necessity to address the impact of cultural and political systems on the disciplinarity of science.

Institutions, Politics, and Money

The conclusion of analyzing the demarcation between disciplines is not surprising. There does not seem to exist particular philosophical criteria which distinguish disciplines from one another. However, each discipline has a unique relationship with the philosophy of science. Science, it is clear, is not a uniform epistemological practice. The broad established disciplines are not in themselves homogeneous in their subjects of study, theories, methods, or interpretation. Given this conclusion, the easiest answer for the demarcation of disciplines is not some philosophical or epistemological concept with necessary and sufficient criteria. Instead, disciplines, as they are most often viewed, are the results of institutions, politics, and money. Thus far, this paper has avoided talking at length about these more culturally-defined constructs; however, for the current question of how disciplines are demarcated and organized it is essential to address the institutional categorization of scientific disciplines.

Science, through its applications and reputation, has a significant impact on society; however, the impact of society on scientific practice cannot go unacknowledged. This topic is not the main focus of this paper, but it is important to cover certain aspects which specifically impact the vector of science and the demarcation of disciplines. First, one may examine the impact of research funding. Second, one may examine the nature of scientific education. Third, one may examine the process of scientific dissemination. Finally, one may examine the impact of politics and political movements on scientific practice. These analyses will be overviews to establish important factors of the question at hand.

Today's scientific research is mostly conducted out of research universities and funded by government grants. Funding, for the purposes of this exploration, refers to the funds utilized for any expense and includes access to necessary equipment and technology. The views of universities and even the grants themselves perpetuate and maintain established disciplines. Regardless of any changes to a discipline's subjects, theories, methods, or interpretation, universities and other establishments can neatly accommodate small changes without much uproar. Instead of establishing subdisciplines based on philosophical criteria, universities create a new department when there is a particular demand for one. This is often related to, but not entirely defined by, access to equipment and availability of funds. Stichweh discusses the discipline specialization and the creation of more subdisciplines as a result of the scientific community. Modern universities are, thus, a tool for communication within the scientific community and the most convenient way of establishing and communicating the distinctions between science and non-science as well as between different scientific disciplines[113].

This is further complicated however when one considers the scientific ethos of Mode-2 knowledge production. For one, the university is not the only location for prolific scientific research and industry and private research can more often live up to the Ziman norms than the Merton norms. Second, even with the university system certain elements of Mode-2, despite

[113] Rudolf Stichweh, "History of Scientific Disciplines," in *International Encyclopedia of the Social & Behavioral Sciences* (Amsterdam: Elsevier, 2001), pp. 13727-13731.

being essentially post-academic, assert a certain level of influence. Significant to this discussion is the consensus that this more practical, proprietary science is more transdisciplinary and lacks the institutional entrenchment of established disciplines in its problem-solving pursuit[114].

In addition to funneling and distributing government funding, universities control most of scientific education and the training of new researchers in the individual fields[115]. Reinforcement of established rules and procedures within disciplines is not unique to modern universities. These behaviors and procedures, perpetuated by universities, are socially defined rather than philosophically defined though the two ideas are deeply connected. Regardless of any student's intention to participate in research, curricula are also established with the disciplinary structures in mind. Disciplines, at universities, are defined as much by research and research training as by education itself. Thus, these two constructs are inherently linked. It would be prudent to distinguish between a department and a discipline. Departments are university constructs which often hold the same titles as disciplines. Disciplines are much broader than universities but tend to be driven by the departments[116]. Professors at universities are often asked to do research as well as educate; however, not all students within a department are training to become researchers in that discipline themselves, especially in disciplines which have specific and direct real-world applications. Of course, there are some geographical and hierarchical dependencies. So, remaining focused on American universities and undergraduate curricula in particular, one can see that many students in the department of biology, for instance, are not intending to become

[114] Michael Gibbons et al., *The New Production of Knowledge the Dynamics of Science and Research in Contemporary Societies* (Los Angeles, CA: Sage, 1994).
[115] Evgeniy Bryndin, "Creative Innovative Higher Education of Researchers with Flexible Skills and Synergy of Cooperation," *Scientific Journal of Research & Reviews* 1, no. 2 (2018), https://doi.org/10.33552/sjrr.2018.01.000507.
[116] Rudolf Stichweh, "History of Scientific Disciplines," in *International Encyclopedia of the Social & Behavioral Sciences* (Amsterdam: Elsevier, 2001), pp. 13727-13731.

biological researchers. With this fact in mind, curricula, which are defined by the department, are based on both the current research, values, beliefs, and procedures of a particular discipline as well as the possible career paths of the students within the department. The relationship between departments and disciplines is bidirectional. While the research values and behaviors do impact department curricula[117], the curricula also impact the research behaviors[118]. This relates directly back to the concept of the goals of science or of a particular discipline impacting the research that is conducted. If education is focused on the applied careers in the particular field, then the goals of research may skew in the direction of applicability and thus may be more greatly impacted by Mode-2 expectations. Scientific research is, in the current university system, inextricably linked to scientific education.

Scientific dissemination also has an impact on the conversations thus far; it relates directly to the demarcation of science and the demarcation of disciplines. Stichweh, in addition to recognizing the communicative nature of universities, recognized that the establishment of journals, which related to specific disciplines, could also indicate the scope and role of those disciplines[119]. Modern journals utilize peer review to systematize the scrutiny of the community of scientists disseminating their work. In other words, peer review allows the community to determine where, in an established system, specific scientific behaviors belong disciplinarily[120].

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[117] Melvin J Anderson, "The Scientific Research Method as a Learning Tool in Higher Education," n.d.

[118] Gita Bangera and Sara E. Brownell, "Course-Based Undergraduate Research Experiences Can Make Scientific Research More Inclusive," *CBE—Life Sciences Education* 13, no. 4 (2014): pp. 602-606, https://doi.org/10.1187/cbe.14-06-0099.

[119] Rudolf Stichweh, "History of Scientific Disciplines," in *International Encyclopedia of the Social & Behavioral Sciences* (Amsterdam: Elsevier, 2001), pp. 13727-13731.

[120] Alexander Kaufmann and Andrea Kasztler, "Differences in Publication and Dissemination Practices between Disciplinary and Transdisciplinary Science and the Consequences for Research Evaluation," *Science and Public Policy* 36, no. 3 (January 2009): pp. 215-227, https://doi.org/10.3152/030234209x427121.

This is of course a rather post hoc view of discipline distinction but is nevertheless notable in its ability to harness the community. Additionally, national and international organizations that establish rules about discipline specific dissemination and behavior also influence the behaviors of scientists. For example, the American Psychological Association not only established a democratized governing body for the psychology discipline, but also established a publication format for articles[121]. This format dictated specifically the acceptable way to disseminate work within psychology. These journals, governing bodies, and communities of scientific authors established both the similarities of scientific dissemination and the discipline distinctions.

Finally, the questions about scientific and disciplinary thought as well as the ongoing practice of science has been impacted by historical events, political turmoil, and the personal politics of individual scientists and thinkers. Science has never been particularly apolitical. These political entanglements represent the imperfect implementation of Merton's scientific norms. For instance, the logical positivist movement, which has been discussed at length, began in Vienna; however, the political unrest, racism, and imminent conflict that was World War II led most logical positivists to flee Germany[122]. One thinker, Schlick, was even murdered by a student for political reasons[123]. These political factors disrupted the community and consensus building that the movement had previously possessed. Other thinkers and scientists were also impacted by politics external to the scientific community even in science unconnected with university scholarship. Take for example, the US Superconducting Supercollider which was defunded by

[121] American Psychological Association, *Publication Manual* (Washington, D.C.: American Psychological Association, 2001).

[122] Donata Romizi, "The Vienna Circle's 'Scientific World-Conception': Philosophy of Science in the Political Arena," *HOPOS: The Journal of the International Society for the History of Philosophy of Science* 2, no. 2 (2012): pp. 205-242, https://doi.org/10.1086/666659.

[123] Friedrich Stadler, *The Vienna Circle: Studies in the Origins, Development, and Influence of Logical Empiricism* (Cham: Springer, 2015).

congress. Debates on the very nature of science and knowledge were conducted in front of congress and ultimately, the politics of non-scientists determined the fate of that scientific project[124]. The external politics and events may not dictate as strictly the distinctions between disciplines; however, these factors affect how, when, and with what motivation science is done. These external factors, thus deeply impact the vector of science.

Conclusion

The socially and culturally defined structures as well as the external circumstances make a difference to the question of discipline distinction and more broadly the function of disciplines in science. It is easy, after the discussion of discipline demarcation, to suggest that the vector of science is most impacted by the political and cultural structures that directly drive the practice of science. However, this would ignore the significant entrenchment of philosophical beliefs on scientific behaviors. Consequently, the vector of science and future scientific behavior is impacted by the philosophy of scientific inquiry, the philosophies of particular disciplines, and sociopolitical factors.

As no clear criteria for distinguishing disciplines is forthcoming, each discipline engages in very different activities and maintains thoroughly unique philosophical values. One might even say that these disciplines are incommensurable. Thus, the question that is left is how do these different disciplines and subdisciplines interact with one another considering the challenges of incommensurability. In a conclusion and culmination of the explorations thus far, this paper will analyze the ways in which science might transcend, accept, and engage with disciplinarity. Disciplines, it seems, are here to stay and while their function may not be clear, their importance

[124] John H. Marburger, “The Superconducting Supercollider and US Science Policy,” *Physics in Perspective* 16, no. 2 (2014): pp. 218-249, https://doi.org/10.1007/s00016-014-0133-9.

to the perpetuation of science is undeniable. If the future of scientific research is interdisciplinary, what would this research look like? The final section will explore the vector of science through the lens of interdisciplinarity and the ingrained beliefs about the function of scientific disciplines.

Conclusion

The question central to this paper has been exploring the function of disciplines within a scientific system. The exploration of the demarcation of science itself and of the disciplines it contains is an important precursor to understanding the function of disciplines and of the placement and integration of interdisciplinary work within that system. Throughout this paper the structure that has been used to compare and describe science and its disciplines is that of subjects, theories, methods, and interpretation. This structure was chosen for its concise and comprehensive view of the behaviors of traditional science. This structure contains within it both the very abstract, philosophical components of scientific practice and the concrete, historical behaviors of scientific practice.

These explorations reflect a wide-angle lens approach to the problem at hand and the conclusions are thus broad. Science is something of a socially defined practice with many of its ethos tied to but not defined by specific behaviors and beliefs. The function of disciplines within a scientific system remains an elusive conclusion being similarly described by its philosophical ethos. However, the exploration of both science and disciplines is enlightening with regard to interdisciplinary research. Interdisciplinary research faces many challenges because of the ways that science and scientific disciplines are constructed. Scientific disciplines, without careful understanding of the philosophical divides, are rarely able to address the differences in their subjects, theories, methods, and interpretation. To combat deep philosophical and metaphysical divides between disciplines in their pursuit of interdisciplinarity, as shall be shown, the disciplines might work on their comparability, parity, and synergy to be more philosophically aware in interdisciplinary pursuits. The perpetuation of science through time, the vector of science, is influenced and driven by the philosophical and social behaviors of science as each experiment, belief, controversial thinker, and political influence impacts the science that will be done next and on through time. Thus, the disciplinarity of science has a significant impact on the vector of science.

This paper explores the inherent and historical disciplinarity of science and its connection with interdisciplinarity moving forward. However, only so much of the debates and discussions can be explored. Therefore, further research into the function of disciplines in science would be prudent, especially with regard to any institutional and political proposals based on achieving disciplinary functionality. Additionally, more research is needed on the logistical and practical aspect of implementing philosophically aware interdisciplinary research[125].

Philosophically aware interdisciplinary research is the conclusion of the philosophical complexity previously discussed. As is well-established at this point, disciplines are remarkably distinct. While occasionally they have similar features from which they can be categorized, the prevailing conclusion is that disciplines have their own unique subjects, theories, methods, and interpretation. This is both the result of a lack of consensus surrounding what is considered scientific behavior at all and the unique relationships each discipline has with the philosophy of science. Furthermore, disciplines are divided by political, traditional, and financial factors. Even within traditional disciplines, there are aspects of distinction which separate the work further into subdisciplines. Scientific disciplinary behavior is often dependent on how each discipline incorporates the beliefs of historical thinkers and movements. Additionally, one can wonder about ideological entrenchment which would only enhance the divides between disciplines.

[125] Norman Metzger and Richard N. Zare, “Interdisciplinary Research: From Belief to Reality,” *Science* 283, no. 5402 (1999): pp. 642-643, https://doi.org/10.1126/science.283.5402.642.

The main goal of this paper is to highlight the significant differences and hierarchies between disciplines. The organization of these disciplines and the beliefs that hierarchies create change the dynamics between disciplines. The only implementable solution for interdisciplinary or transdisciplinary research addressed in this paper has come from the Mode-2 knowledge production[126]. However, with this conception comes other expectations which are not connected to the disciplinarity or interdisciplinarity of the work, such as a focus on the practical application and a lack of cooperative sharing of findings and knowledge. Furthermore, due to the integration of the beliefs into the university, institutions and educational entrenchment of disciplines still has an impact on the behaviors of scientist even as expert problem solvers. The discipline training, beliefs, and biases are still present in individuals even when the approach itself is transdisciplinary. It seems that there should be a possibility for interdisciplinary research that could still exist within the academic space and could, regardless of its driving mode, unpack and utilize the disciplinarity of individuals and systems.

Comparability, Parity, and Synergy in Interdisciplinarity

Based on the explorations and conclusions of the preceding discussions, the following framework for interdisciplinarity in the academic space that honors individual biases and perspectives is proposed. This framework will contain many normative beliefs and assertions about interdisciplinary research. Additionally, the following paragraphs will give more specific, contextual definitions of words that are colloquially defined including comparability, parity, and synergy in order to structure these normative assertions. Kuhn’s incommensurability, applied to individual disciplines, suggests that disciplines do not observe the same reality, value the same

[126] Michael Gibbons et al., *The New Production of Knowledge the Dynamics of Science and Research in Contemporary Societies* (Los Angeles, CA: Sage, 1994).

questions, or speak the same language which would make their cross-sectional work particularly challenging[127]. Interdisciplinary research is complicated, delicate, and multifarious[128]. There are many ways to achieve interdisciplinarity without compromising the strides and contributions of individual disciplines. The principles of comparability, parity, and synergy are an assertion about possible perspective steps to effective interdisciplinary research based on the philosophical and behavioral divides between scientific disciplines outlined in this paper. These three words represent concepts that are interdependent and build upon one another. Thus, one would need to start with comparability in order to achieve parity and synergy. As stated, this is a possible framework for interdisciplinarity based on the philosophical understanding of disciplines established thus far.

Comparability is the understanding of the differences in philosophy, values, and behaviors between disciplines and the understanding that scientific disciplinarity creates limited perspectives. Disciplines are comparable when each discipline's unique and individual perspective is understood by the other disciplines. Comparability would be, for example, the understanding of incommensurability between disciplines which are generally perceived as requiring effortful deconstruction of differing philosophies, methods, and language. Each of the categories would also need to be addressed in comparability – the subjects, theories, methods, and interpretation – and how these factors differ and intersect. Additionally, as evidenced by the educational connection, disciplinarity is incorporated into not only the practice of science, but

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[127] Paul Hoyningen-Huene, "Kuhn's Conception of Incommensurability," *Studies In History and Philosophy of Science Part A* 21, no. 3 (September 1990): pp. 481-492, https://doi.org/10.1016/0039-3681(90)90006-T.

[128] Lisa M. Campbell, "Overcoming Obstacles to Interdisciplinary Research," *Conservation Biology* 19, no. 2 (2005): pp. 574-577, https://doi.org/10.1111/j.1523-1739.2005.00058.x.

into the training of scientists[129]. This training is one example of the creation of a limited perspective. Scientists are trained within their discipline and imbued with the beliefs and values of that discipline. Comparability is achievable through understanding a limited perspective and the differences between one's particular perspective and another's. Comparability is just one factor which would help combat the incommensurability and deep divides between disciplines.

Parity is the mutual respect and perceived equality between the differing perspectives of scientific disciplines. Parity represents a fundamental belief that though a particular scientific behavior may differ from one's own behavior, neither behavior is superior or more scientific than the other. This stems from the belief that there is no consensus on what defines science, and that each discipline interacts with the philosophy of science differently. Popper, for example, may indicate a hierarchy from more scientific practices to less scientific practices; however, rigidity to this belief would stifle parity between disciplines[130]. Parity is the belief that all disciplines have limited and equally valuable contributions to interdisciplinary science. Furthermore, parity indicates the acceptance, within the critical necessity of the scientific community, of the results of other scientific disciplines despite philosophical differences. Anderson, in his criticism of theory reductionism, addresses the concept of parity. Anderson's argument suggests that, because of their unique, underivable contributions, none of the disciplines can really be considered more fundamental than any other[131]. Parity also asserts that

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[129] Bryndin, "Creative Innovative Higher Education of Researchers with Flexible Skills and Synergy of Cooperation,"

[130] Karl Raimund Popper, *The Logic of Scientific Discovery* (Vienna: Logik der Forschung , 1935).

[131] Philip W. Anderson, "More Is Different," *Science* 177, no. 4047 (August 4, 1972): pp. 393-396.

no scientific discipline is fundamental, and the unique contribution of each discipline should be taken as equally valuable to scientific discourse and to interdisciplinary research.

Synergy is the act of cooperation between disciplines in interdisciplinary research after achieving comparability and parity. This may be the most complex step as it requires specific decisions on the subjects, theories, methods, and interpretation that will be used in the interdisciplinary work. Synergy with the precursors of comparability and parity would indicate that those decisions would be made from a philosophically and disciplinarily informed place. Synergy also indicates that interdisciplinarity does not operate in isolation. A single discipline cannot effectively engage in interdisciplinary research without consulting and collaborating with other disciplines as there would be inadequate comparability and parity. This is due to the limited perspective of individual disciplines. Thus, the choices of synergy are achieved through collaboration with comparability and parity between the collaborating disciplines. Synergy is the final act of collaboration itself and the closest thing in this framework to a truly practical implementation. Thus, this is where most of the recommended future study lies – in the practical pursuit of collaborative synergy.

These factors that contribute to achieving interdisciplinary research are derived from the deep divides between disciplines and the lack of consensus about what constitutes scientific behavior. Interdisciplinarity is a tremendously popular idea in science, and it is unlikely that careful attention is being paid to philosophical and behavioral divides, to limited perspectives, and to hierarchical entrenchment. Of course, there are still practical, logistical concerns with interdisciplinary research especially within modern political and institutional systems. However, the philosophical challenges cannot go unacknowledged.

The Vector of Interdisciplinary Science

The vector of interdisciplinary science is tough to discern. The implications of the proposed interdisciplinary factors just discussed are interesting as they relate to the vector of science.

As previously discussed, the conclusion that one can come to with regard to disciplinary vectors of science is that individual disciplines require their own independent conception of the vector of science which may look different than the overall vector of science. To stretch the metaphor perhaps too thin, it may be interesting to view interdisciplinarity as the unique mathematical relationships between two vectors. It is well established that simple addition of constituent parts is insufficient for interdisciplinarity so would interdisciplinarity look more like the addition of two vectors. When two vectors are summed both the magnitude and direction will be affected not wholly independently from one another. As stated, this may be stretching the metaphor a little over its limit especially as these are not mathematical entities, but it does highlight the ways in which the vector of interdisciplinarity is more complex than even the summation of disciplinary vectors.

This highlights the necessity of exploring the magnitude and direction of the vector of interdisciplinarity separately. The magnitude is the energy, prolificacy, and Lakatosian progression with which the science is being pursued. This paper began with the assertion that interdisciplinarity was the hot topic in scientific communities; everyone is interested in doing interdisciplinary scientific research, but not everyone is showing particularly interesting interdisciplinarity[132]. Thus, it seems that magnitude or at least the demand for interdisciplinary research is remarkably strong.

Next it is important to explore both factors for the direction of the vector of interdisciplinarity: the directional next and the trajectory of interdisciplinarity. For interdisciplinary research, the directional next would be based on the chosen elements from synergy and would be directly related to the structures and dynamics of the collaboration. The choices made for research subjects, theories, methods, and interpretation would depend on how well individual scientists have integrated the beliefs of comparability and parity into their professional beliefs. For instance, if a scientist maintains a belief about the exceptionalism of physics in comparison with other sciences, they have not completely integrated the principles of parity. As a result, this scientist would likely choose to pursue a directional next answering their interdisciplinary question with physics-based methods and values. Thus, the vector of science would more directionally match the vector of physics. Of course, this example describes the impact of only one scientist and as stated, successful synergy is based in collaboration between multiple scientists with unique disciplinary backgrounds. However, each scientist's beliefs are relevant to the interdisciplinary choices they make and to the subsequent directional next.

Furthermore, there has been examples that interdisciplinarity in the past has followed the same principles as subdisciplinarity. Often, successful interdisciplinary fields become their own disciplines as the chosen procedures and beliefs become widespread and standardized enough to be categorized[133]. This is an example of how individual choices for the directional next and their

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[132] Michelle Appleby, "What Are the Benefits of Interdisciplinary Study?," OpenLearn (The Open University, March 1, 2019), https://www.open.edu/openlearn/education/what-are-the-benefits-interdisciplinary-study.

[133] Gabriele Bammer, "Should We Discipline Interdisciplinarity?," *Palgrave Communications* 3, no. 1 (2017), https://doi.org/10.1057/s41599-017-0039-7.

impact on the vector of interdisciplinary science imply a long-term trajectory of interdisciplinary science. By valuing disciplinarity and standardizing certain beliefs and behaviors, one sees a trajectory of interdisciplinary science where work that is now interdisciplinary will one day be an independent discipline. One is left wondering whether these new disciplines, born from interdisciplinarity, will be indistinguishable from other disciplines or if some factor will mark them as uniquely interdisciplinary. Furthermore, is the subdisplinization of interdisciplinary work as positive trajectory for continued interdisciplinarity?

The vector of interdisciplinary science is unique in its reflection of the interconnectedness of disciplinary values. As more disciplines formulate and pursue interdisciplinary questions and thus tackle the philosophical and perspective challenges with interdisciplinary work, it is likely that new implications for the vector of science will be revealed. The unique quality of interdisciplinary work and collaboration is the ability for unforeseen and novel ideas to emerge from the intersections of those disciplinary vectors. Thus, the conclusion is that the vector of interdisciplinary science is to a certain extent unpredictable as true pluralistic collaboration is particularly variable. This is why exploration of interdisciplinarity is useful as a culmination and conclusion to the disciplinary exploration that this paper has achieved. Disciplinarity in science is the basis, the mechanism, and the framework of interdisciplinary research.

Sign Off

As science continues to change and grow, it is important to take a step back and address the broad philosophies, behaviors, and expectations that drive scientific practice. Especially as one thinks of the continuation of that practice on through time. One is left to wonder of predicting the future. What will be uncovered next? What technological advances will be invented? Where will science go and will it recognize itself as it goes?

Predicting the future is an impossibility that one may spent a lifetime tackling because is it not just so science to spend a lifetime tackling an impossibility. The vector of science is an instantaneous and delicate metaphor, but it serves as a reminder that the direction that science faces now is not the same direction it has always faced nor is it the direction it will come to face. The slightest action can change the direction of the vector of science and throw more uncertainty into predicting the future.

It is humbling to remember that one will almost certainly be incorrect in their prediction of the future, but it is empowering to know that the slightest impact, the smallest discipline, and the radical thinker can change the direction of science even for an instant.

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