MECHANISTIC CRIMINOLOGY

K. Ryan Proctor and Richard E. Niemeyer

EVOLUTIONARY ANALYSIS IN THE SOCIAL SCIENCES

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The science of criminology is at a crossroads. Despite accumulating a dizzying array of facts about crime, the field has yet to identify a body of theories that allows for the adequate prediction, explanation, and control of phenomena of central interest to criminologists. *Mechanistic Criminology* locates this problem within the field's failure to conform to the expectations of scientific fields and reliance on antiquated methods of theory construction. The authors contend that this failure has resulted in an inability of criminologists to engage in theory falsification and competition—two central activities of science—that produce the forms of reliable knowledge that are unique to scientific fields.

Mechanistic Criminology advocates for the adoption of a mechanistic mode of theorizing to allow criminologists to engage in theory falsification and competition and ignite rapid scientific discovery in the field. The proposed method is the same one employed within the biological sciences, which is responsible for their rapid scientific progress in the late twentieth and early twenty-first centuries. Should criminologists adopt this mechanistic approach, criminology could experience the same scientific revolution that is occurring in the biological sciences, and criminologists would generate the knowledge necessary for the prediction, explanation, and control of crime.

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This book represents the development of many years of thinking about how to improve the scientific enterprise within criminology. We fully acknowledge that we are not the first to attempt to improve scientific rigor within the field. Criminology's history is one of countless individuals who have diligently worked, persisted, and offered invaluable insights in the ongoing effort to establish, maintain, and further develop a scientific criminology. We also acknowledge that the theoretical method we propose in this book will inevitably fall short of its aims and our ambitions, as science is inevitably a collective endeavor and not an individual one. Nonetheless, like many other criminologists, we believe science gives criminology the best hope for predicting, explaining, and controlling the social phenomenon of crime.

Just as science is a collective endeavor, so too is the authoring of a book. Both authors owe a tremendous debt to those professors who significantly contributed to their intellectual development while earning doctorate degrees in sociology from the University of California, Riverside (UCR). Peter J. Burke greatly influenced both authors throughout our graduate training by introducing us to theoretical methods and formalism. For Richard E. Niemeyer, who also earned his bachelor's degree at UCR, Peter significantly influenced Richard's career trajectory by inspiring him to become a sociologist. Contrary to Peter J. Burke's theoretical approach, which emphasizes the use of scope and boundary conditions when constructing theory, Jonathan H. Turner also profoundly influenced both authors' growth as social scientists. Jonathan H. Turner's emphasis on general theory and theory integration between various scientific fields inspired both authors to look beyond the narrow confines of sociological thought when attempting to explain social phenomena. Jonathan H. Turner served on both authors dissertation committees, and strongly influenced Ryan's ideas on theoretical formalism. He also strongly encouraged and nurtured Richard's passion for theory and penchant for ignoring disciplinary boundaries. Richard would also like to thank his friend and colleague, David Franks, for introducing him to the field of neurosociology, and for all of David's stories about model airplanes and his days as an amateur boxer.

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Part I

SCIENTIFIC CRIMINOLOGY

Introduction

> Not only is this body of information [criminology] of no etiological significance, but it is useless from the point of view of the major practical problems of crime, since control of crime depends upon knowledge of its causes.
>
> (Jerome Michael and Mortimer J. Adler 1933:54)

In the early 1930s, Jerome Michael and Mortimer J. Adler (1933:54) authored the famous Michael-Adler report, which assessed the desirability of creating a research institute of criminology and criminal justice within the United States. The key finding of their study was that criminology had yet to develop into a basic science, and that this fact was particularly troubling because the reliable control of crime ultimately rested upon the development of a body of scientific knowledge that explained it. In the absence of such a stock of knowledge, Michael and Adler contended that applied science would be nothing more than an exercise in trial and error, one that was poorly suited for effectively controlling crime.

Nearly 100 years after this report, questions remain surrounding criminology's efficacy as a science. There should be little doubt in the minds of criminologists that the field has produced a dizzying array of facts surrounding the correlates of crime over the last several centuries (see, e.g., Ellis, Beaver and Wright 2009). Unfortunately, criminology has been far less effective in developing a body of theoretical knowledge capable of explaining why various things correlate with crime, or resolving the numerous paradoxes inherent to a field that recognizes the validity of multiple competing and contradictory explanations of crime.

Answering questions about criminology's performance as a science is no doubt a difficult task. This task is particularly challenging because criminology is a highly divided field; there is not even a consensus as to whether criminology can or should be a science (Agnew 2011), let alone what a definition of science might look like. Disagreements over the status of criminology as a science, unfortunately, tend to see criminology as only capable of being one thing or another—as being either scientific or nonscientific—and many have attributed this dualism within criminology to having undermined the field's rate of scientific progress (see, e.g., Tittle 1985). We disagree with this assertion and instead observe that the fundamental obstacle to scientific criminology has been deficiencies within scientific criminology itself, not the corrupting influences of nonscientific criminologists.

This claim, of course, is not without controversy. Those operating within a scientific framework have labored extensively for over a century to produce knowledge about crime. Despite these efforts, serious criticisms exist surrounding the current stock of scientific knowledge within the field, with perhaps the most significant criticism being that criminological theories are weak at explaining crime (see, e.g., Weisburd and Piquero 2008). This criticism is not new. Following the era of what John Laub (2004) has called the 'Golden Age of Theory,' a period occurring between 1930 and 1960, criminological theory has mostly been seen as being in the doldrums. The 1970s and 1980s saw a period in which integrated theories attempted to advance scientific knowledge, but these theories were harshly rebuked for their logical inadequacies. In the 1990s a new wave of theories—such as self-control theory (Gottfredson and Hirschi 1990), general strain theory (Agnew 1992), and control balance theory (Tittle 1995)—created a new sense of optimism for criminological theory.[1] This optimism, however, was short-lived and by the 2000s concerns over theoretical progress within criminological theory were again renewed (see, e.g., Bursik 2009; Cullen 2011; Laub 2004, 2006; Weisburd and Piquero 2008; Wright and Cullen 2012). At present, there is a general sense of malaise surrounding criminological theory, and an open secret within the field is that few are genuinely satisfied with the current stock of scientific criminological theories.

The purpose of this book is to explicitly identify and address the many issues plaguing scientific criminology in the hopes of facilitating a renewed interest in criminological theory, one that will spur the field's scientific advancement. Of course, we are not the only criminologists attempting to address this problem. Over the last two decades, biosocial criminology (e.g., Beaver, Barnes and Boutwell 2015; Walsh 2002; Walsh and Beaver 2009a; Wright and Cullen 2012) and analytical criminology have been leading intellectual movements that attempt to advance criminological theory. A commonality between both movements is that they seek to resolve theoretical fragmentation in the field; that is, the overabundance of competing, contradicting, and empirically weak theories of crime.

Biosocial criminology's solution to theory fragmentation rests upon an interdisciplinary criminology that transcends the field's traditional sociological orthodoxy to promote explanations of crime that include and integrate insights from evolutionary psychology, genetics, neuroscience, and the social sciences (Walsh and Beaver 2009b). Biosocial criminology advocates for a vertical integration of the sciences (see, e.g., Walsh 2002) in which theories and findings from various scientific fields are used to facilitate theory falsification and integration, as well as discovery, within criminology. Biosocial criminologists contend the approach can facilitate this scientific progress by opening up the field to new discoveries (since it does not solely rely on sociological insights), introducing it to the advanced methodologies of the other scientific fields (particularly those within the biological sciences), and increasing the precision of existing criminological theories by further specifying their underlying biological and psychological mechanisms (Wright and Boisvert 2009). Ultimately, biosocial criminology argues that for scientific progress to occur within criminology, the field must adopt a new paradigm of science (see, e.g., Walsh 2009).

Like biosocial criminology, analytical criminology (Treiber 2011; Wikström 2006; 2010; 2014; Wikström and Treiber 2009)—as part of a more general movement to improve scientific sociology known as analytical sociology (Demeulenaere 2011; Hedström 2005; Hedström and Bearman 2009; Hedström and Swedberg 1998; Manzo 2014)—has sought to promote theoretical progress within criminology. Unlike biosocial criminology's emphasis on establishing a new criminological paradigm, analytical criminology offers a general theory of crime—situational action theory—that attempts to resolve theoretical fragmentation by offering a single theory capable of explaining the correlates of crime. It doing so, analytical criminology advocates that a good theory elucidates the key mechanisms that produce crime. Unlike biosocial criminology, which locates criminology's fragmented state with its reliance on sociological theories of crime and inability to engage in theory falsification (see, e.g., Walsh 2009), analytical criminology attributes criminology's fragmentation to the field's overreliance on statistical modes of explanation (see, e.g., Wikström 2006).

While both approaches represent rigorous and valid efforts to improve scientific criminology, we contend that each *alone* is insufficient for spurring scientific progress for several reasons. First, neither approach adequately attempts to reconcile longstanding issues that have prevented scientific progress. Where biosocial criminology locates criminology's scientific stagnation in its stubborn refusal to incorporate non-sociological insights, analytical criminology interprets criminology's scientific failure as being a result of its over-reliance on correlative approaches. While both observations are in fact true, both only capture a small portion of the various factors that have impeded scientific progress in criminology. As noted by Hirschi (1989), criminological theories have historically advanced as part of an oppositional tradition in which theories would be constructed with the often explicit intention of contradicting the logical premises of rival theories, with the intention being that theories could be tested against one another and falsified theories would be discarded. By the 1970s, however, the traditional method of scientific progress involving theory competition had failed within criminology: Theories were not being falsified, and integration efforts started to emerge that sought to create unified explanations of crime. These integration efforts largely focused on utilizing multiple criminological theories simultaneously to maximize the explained variance of crime within statistical models (see, e.g., Elliot 1985; Elliot, Ageton and Canter 1979; Elliot, Huizinga and Ageton 1985), efforts that were sharply criticized for their failure to actually logically integrate the theories included within the models from which variables were derived (see, e.g., Hirschi 1979; 1989; Liska, Krohn and Messner 1989). Biosocial criminology has attempted to facilitate both falsification and integration in criminology; however, its reliance on risk factor approaches has meant that it has mostly neglected to address the logical problems inherent to theory integration (Schwartz 2014).[2] Analytical criminology has been silent on both the issue of falsification and integration.

Second, neither biosocial nor analytical criminology provide a clear conception of what science is or how a definition of science might be used to improve scientific criminology. Biosocial criminology is correct in its assertion that criminology should borrow insights from neighboring scientific fields, a property of science referred to as systemicity (Mahner 2007). Analytical criminology is correct in its assertion that scientific explanations should exhibit realism and actually explain reality (Wikström and Treiber 2014), which is a key assumption of reality referred to as the correspondence principle of truth (Mahner 2007). These are but two properties of science, and if scientific criminology is to be improved, it is vital that criminologists fully understand what it means to be a science and how knowledge of the various properties of science can be used to promote theory development.

Third, biosocial criminology and analytical criminology both rely heavily upon the use of the concept of mechanisms to explain crime, but neither approach actually defines what mechanisms are and what role they play in scientific explanations of phenomena with any detail. Biosocial criminology sees biological mechanisms as being the source of many of criminology's 'usual suspects' that correlate to crime—such as age, race, and gender. But because biosocial criminology eschews the development of a theoretical method for articulating scientific explanations (Wright and Boisvert 2009), it is unclear what mechanisms are, how one would go about constructing explanations with them, or how the idea might differ from other modes of theorizing, such as the logical-deductive formalism advocated by Gibbs (1972). Analytical criminology is on much firmer ground than biosocial criminology in regard to mechanisms, mainly because it explicitly borrows the concept of mechanisms from the philosopher of science, Mario Bunge (e.g., Bunge 2006). Nonetheless, analytical criminology never elaborates the concept of a mechanism with any depth or indicates how mechanistic approaches differ from other, non-correlative, approaches to theory construction. To acquire such information, one must either turn to the writings of Bunge directly, or consult the growing literature in analytical sociology and make inferences surrounding the degree to which analytical criminology subscribes partially or whole-heartedly to the philosophy of Bunge or analytical sociology.

The insights derived from biosocial criminology and analytical sociology could significantly enhance scientific criminology if we were to have a better understanding of: (1) why scientific criminology has failed historically; (2) what precisely mechanistic explanations are and how to formulate them; and (3) how the mechanistic approach can be leveraged to enhance both existing criminological theories as well as the construction of new ones.

Throughout this book, we develop each point. In Part I, we provide a more comprehensive assessment of scientific criminology than currently offered by either biosocial or analytical criminology. We begin in Chapter 1 by drawing heavily from Mahner (2007) to provide a definition of science that identifies the various properties scientific fields exhibit, as well as articulate distinctions between basic science, applied science, and technology. In Chapter 2 we provide an analysis of how well scientific criminology does in exhibiting these properties so as to identify potential areas for improvement. Within Chapter 3, we discuss the nature of scientific knowledge and how scientific fields go about producing it. In doing so, we borrow from the sociology and philosophy of science to discuss how scientific fields seek to produce cumulative knowledge claims—which are non-paradoxical claims about reality that allow for the prediction, explanation, and control of phenomena—through various forms of empirical observation. Chapter 4 takes this discussion and evaluates scientific criminology in terms of its ability to produce cumulative knowledge claims. Given the failure of criminology to produce such statements, we also discuss the alternative strategies criminologists have employed when attempting to facilitate scientific progress.

Part II of the book proposes a mechanistic approach to theorizing or knowledge claim construction that we contend can radically advance the development of scientific criminology, potentially leading to a second golden age of criminological theory development. Chapter 5 works toward this end by providing an overview of what mechanistic explanations are, how they explain phenomena, and how they differ from other modes of scientific theorizing. Chapter 6 extends our discussion of mechanistic explanations to specify how mechanistic explanations—*or mechanism schemas*—are constructed, evaluated, and revised when explaining phenomena. For both Chapters 5 and 6, we draw heavily from new mechanical philosophy of science, particularly the mechanistic philosophy developed by Machamer, Darden, and Craver (Craver 2007; Craver and Darden 2013; Darden 2006; Machamer, Darden and Craver 2000). Since this philosophy of science was developed to explain the rapid scientific progress of the biological sciences, and biosocial criminology seeks to integrate complex biological and social phenomena, we believe insights from this approach can be particularly useful in promoting a unified criminology. We conclude Part II with Chapters 7 and 8 that provide thorough discussions of why we believe biosocial and analytical criminology are limited in their abilities to spur scientific progress within scientific criminology.

In Part III of the book (Chapters 9, 10, and 11), we translate social learning, social control, and general strain theories into mechanism schemas as a first step in demonstrating the benefits a mechanistic approach might have for scientific criminology. We choose these theories for two reasons. First, these theories have historical roots within debates that occurred throughout the late 1970s, 1980s, and 1990s surrounding how criminological theory should be advanced considering the failure of the field to falsify existing theories. A major component of this debate was the argument that the lines of theory emerging from the oppositional tradition of theory construction could not be integrated because they contained contradictory assumptions that served as a barrier to theory integration (see Hirschi 1979; 1989; Liska, Krohn and Messner 1989). Since mechanism schemas are not logical deductive statements about reality, by translating these three theories into mechanism schemas, we can begin to explore new opportunities for integration—opportunities that rest within each theory's reliance on common underlying mechanisms. We identify learning and role-taking behavior to be but two of the many possible underlying mechanisms shared by each theory. Second, social learning, social control, and general strain theories each represent different modes of theorizing, and by converting each into a mechanism schema, we can demonstrate how criminologists can move between different theoretical formats. Social learning theory (Akers 2009), for example, represents a processual explanation of crime that largely neglects the concrete entities that are actually involved in learning, an intellectual debt it owes to its historical origins in pragmatism and process philosophy. Social control theory (Hirschi [1969] 2002) represents a logical-deductive mode of theorizing, one that claims truth is derived from logical statements about reality. And general strain theory (Agnew 2006) represents a multifactor mode of theorizing where conceptual categories are used to neatly organize various factors that moderate the likelihood individuals will engage in criminal coping behavior, without regard for how the indicators themselves might be tied to common concrete mechanisms that threaten the validity of the conceptual categories the theory employs. Following from these two reasons, in Part III we translate social learning, social control, and general strain theories into mechanism schemas and identify the roles learning and role-taking behavior play in each.

Part IV of the book demonstrates the benefits of adopting a mechanistic approach for promoting systemicity, integration, and falsification within criminology. In Chapters 12 and 13, we discuss how nondeclarative and declarative forms of memory are phenomena that underlie the concepts and explanations of crime proposed by social learning, social control, and general strain theories. In doing so, we draw from the fields of cognitive psychology and neuroscience to concretely specify how each form of memory is distinct, both in terms of how different forms of memory are produced depending upon the learning mechanism involved, as well as in relation to the neuroanatomy involved in each form of memory and learning. We then examine connections between the forms of memory and learning identified by cognitive psychology and neuroscience and notions of learning and memory that are either explicitly or implicitly present within social learning, social control, and general strain theories. In doing so, we identify potential points of defensible integration and note instances in which conceptions of learning and memory within these criminological theories have been falsified. In Chapter 14 we discuss how the phenomenon of theory of mind within cognitive psychology and neuroscience can subsume traditional notions of role-taking behavior that are present within criminology and provide another avenue for potential integrations and falsifications.

We conclude the book by proposing mechanistic criminology as a theoretical method that is capable of promoting defensible theory integrations and competitions within criminology, and therefore the development of cumulative knowledge claims as well. Ultimately, the aim of mechanistic criminology is to foster a basic science of crime that allows for criminology to also more effectively operate as an applied science and technology field as well.

Notes

1 We thank Robert Franzese for this observation.

2 Schwartz (2014) attempts to resolve the issue inherent to previous attempts at theory integration within biosocial criminology. We further discuss Schwartz's model of integration in Chapter 7.

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1

WHAT IS SCIENCE?

Introduction

If efforts are to be successful at improving scientific criminology, a first step is to identify the various properties of science that can serve as a rubric for evaluating scientific criminology. Unfortunately, arriving at a satisfactory definition of science has proven elusive; a central problem is how does one differentiate scientific from nonscientific knowledge. Philosophers of science refer to this problem as the problem of demarcation, and they have had little success historically in identifying the necessary and sufficient characteristics that delineate scientific from nonscientific fields (e.g., Kuhn 1962; Lakatos 1970; Popper 1959). This has led many within philosophy to conclude there is no one criterion or set of criteria that necessarily or sufficiently distinguishes scientific from nonscientific fields (Mahner 2007). This inability to distinguish science from nonscience is particularly problematic if we wish to use the unique characteristics of science to improve criminology.

Two general solutions recently have been proposed to address the problem of demarcation. The first solution is to adopt a 'clustering' approach that eschews a classification of science based upon necessary and sufficient conditions (see, e.g., Bunge 1984; 1991; Mahner 2007). Clustering approaches seek to identify the numerous properties of science as a whole and then turn to specific fields to examine the degree to which they exhibit them. The more properties of science a particular field demonstrates, the more scientific it is, and no particular combination of properties can be said to be necessary or sufficient for establishing whether a given field is scientific. The second solution is to sidestep the problem of demarcation altogether and instead focus on creating a heuristic that describes and makes sense of *what scientists actually do* (see, e.g., Craver 2007; Craver and Darden 2013; Darden 1991; 2006; Hacking [1983] 2010). This solution explicitly avoids promoting ideal representations of science that are divorced from its actual practices. These two solutions are not mutually exclusive and can be combined in such a manner as to allow for a definition of science that does not

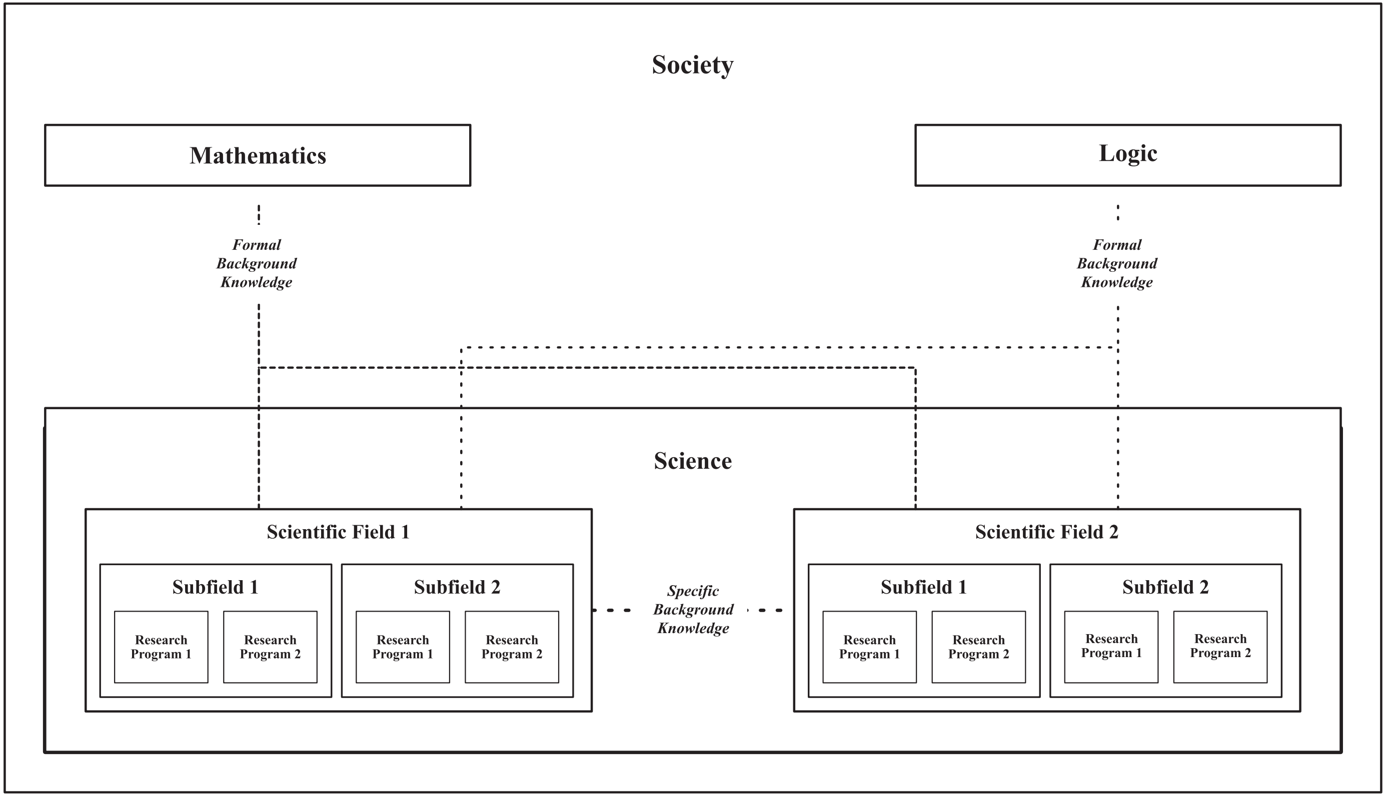

Figure 1.1 The Social Organization of Science

present logical problems, and at the same time does not contain an overly idealized view of the nature of science. Throughout the rest of the chapter, we draw heavily from Mahner (2007) to identify the various characteristics of scientific fields relating to their social organization and philosophical orientations. In the Chapter 2, we then evaluate scientific criminology in terms of its ability to demonstrate these characteristics. We reserve our analysis of the actual activities of scientific fields for Chapters 3 and 4.

Scientific Fields Are Embedded within a Larger Society

The first property of science is that the practice of science is always nested within a larger society. As evident in Figure 1.1, scientific fields do not exist in hermetically sealed chambers and instead are nested within larger societies that can influence their production of knowledge. For a given scientific field to be effective, it must be located within a society that tolerates the scientific field, recognizes the knowledge claims it produces to be factual and true, and refrains from tampering with its efforts to produce knowledge claims (Mahner 2007).

The society in which scientific fields are embedded can influence the practice of science in many ways. Every society contains individuals with political power who may try to influence the 'truths' produced by scientific fields. A government, corporation, or powerful individual may try to influence scientists into promoting falsehoods for legitimacy or political or financial gain. Additionally, and possibly less nefariously, the availability of research funds and funding priorities pertaining to specific scientific fields or research questions may also steer money away from particular lines of inquiry in favor of others and influence the production of scientific knowledge. Things such as the passage of laws that affect the scientific enterprise might also affect the production of scientific knowledge. The 1974 National Research Act, for example, which established federal oversight over human subjects research (see, e.g., Rice 2008), has impacted the ability of scientific fields to produce knowledge claims by placing constraints on the types of research that is possible.

The various stocks of knowledge present in a society can also influence the production of scientific knowledge claims within scientific fields. Language, for example, can be particularly influential in both enabling and constraining scientific fields. A significant challenge posed by language is that all languages are inherently ambiguous and prone to misinterpretation in some way (see, e.g., Derrida 1998). 'Common sense' interpretations of phenomena derived from cultural stocks of knowledge often influence the construction of scientific knowledge claims, even when the knowledge being used is not rigorously scientifically conceptualized (see, e.g., Black 1979). Additionally, nonscientific fields—such as the arts, humanities, and religion—can also influence how scientists think about phenomena.

These are but a handful of examples of the numerous ways in which societies can influence the knowledge produced by scientific fields. The presence of so many potential exogenous influences means that, for better or worse, scientific knowledge claims are always potentially pregnant with nonscientific ideas (Bachelard 2002; Cobb 2006; Harding 1991).

Scientific Fields Possess Specific Philosophical Orientations

Scientific fields are also embedded within a broader community of researchers who are organized under a specific set of philosophical orientations that are unique to science. Science as a whole contains a constellation of numerous, yet highly specific, ontological, epistemological,

Table 1.1 The Philosophical Orientations of Science

Assumption	*Description of assumption or value*
Ontological assumptions	
Ontological realism	Reality exists independently of what humans think about it; all things constituting reality can be studied through scientific investigation.
Naturalism	Only natural entities exist; natural entities can be affected only by other natural entities.
Principle of lawfulness	Reality is not random and instead contains both deterministic and probabilistic regularities.
Principle of antecedence	Insofar as there is a cause of a phenomenon, it must precede its effects in time.
ex-nihilo-nihil-fit principle	'Nothing comes out of nothing, nor does nothing disappear into nothingness.'
No *psi*	One's mind cannot act directly upon the world.
Epistemological assumption—Realism	Reality is knowable; what is knowable can be either observable or unobservable.
Methodological assumptions	
Principle of parsimony (Occam's razor)	Scientific explanations should have as few assumptions as possible pertaining to the things present within an explanation.

Principle of fallibilism	Error is possible in all human activity.
Semantic assumptions—Correspondence principle	Descriptions or explanations of phenomena generated by scientists are true to the degree that they correspond to reality.
Axiological/moral assumptions	
Logical values	Proscriptions against fallacious reasoning within knowledge claims; prescriptions for internal consistency.
Semantical values	Knowledge claims should contain clearly defined concepts; the concepts within knowledge claims should be differentiated from other concepts within the same knowledge claim; concepts within a knowledge claim should be differentiated from concepts outside of the knowledge claim.
Methodological values	Assumptions, methods, and knowledge claims should be testable; criteria should be established for evaluating predictability, explanatory power, and the precision of descriptions or explanations of phenomena; concepts should exhibit fecundity; scientific studies should be replicable.
Attitudinal/moral values	Scientists should be open minded, exhibit objectivity, behave ethically, and think critically.

Source: Mahner (2007).

methodological, semantic, and axiological/moral assumptions that serve as the philosophical orientations unique to science as a field of knowledge production (Mahner 2007). The various assumptions of science are summarized in Table 1.1.

Ontological and Epistemological Assumptions

The ontological assumptions held by the scientific community are numerous and relate to its views about the nature and properties of reality (Mahner 2007). One fundamental ontological assumption of science is *ontological realism*, which holds that reality exists objectively and independently of human perceptions and that the things comprising reality can be studied through scientific investigation. Science also assumes that only natural entities—as opposed to supernatural ones—exist and can affect one another, an assumption referred to as *naturalism*. Science also contains the *principle of lawfulness*, yet another fundamental assumption. This principle holds that reality is not random, but is instead marked by both deterministic and probabilistic regularities. A fourth ontological assumption of science is the *principle of antecedence* that relates to causality. According to this assumption, insofar as a given phenomenon has a cause, the cause must precede it in time. The *ex-nihilo-nihil-fit* principle, which states that 'nothing comes out of nothing, nor does nothing disappear into nothingness,' is a fifth ontological assumption present within science. Lastly, science ontologically assumes the 'no *psi* principle,' which states that the mind cannot directly interact with the material world and that any influence the mind does have is mediated by the motor systems of the human body (e.g., psychokinesis is not possible).

The presence of these ontological assumptions within science comes with several qualifications (Mahner 2007). A first qualification is that the ontological assumptions of science cannot be separated from one another without undermining the underlying logic of scientific inquiry. In other words, they represent a package deal. A second qualification is that the *epistemological assumption of realism* necessarily flows from these ontological assumptions. This assumption holds that reality is knowable, and what is knowable can be either observable or unobservable. This assumption, however, does not specify that reality is perfectly knowable; it merely assumes that reality, at the very least, can be known partially, imperfectly, or approximately. A final qualification is that the ontological and epistemological assumptions present within science represent metaphysical null hypotheses that can be potentially false, and thus the assumptions of science itself are falsifiable. Consequently, these assumptions should not be treated as absolute truths.

Methodological Assumptions

The methodological assumptions contained within science represent the theoretical and philosophical presuppositions that guide and qualify scientific knowledge claim production, with two methodological assumptions being readily observable in all sciences: the principles of parsimony and fallibilism (Mahner 2007). The *principle of parsimony*—commonly referred to as Occam's razor—holds that scientists should begin constructing explanations of empirical phenomena with as few assumptions as possible about the things present in an explanation. The principle of parsimony does not assume that reality is simple, or that simple explanations are desired or even warranted. Such an assumption would be an ontological one. Instead, it merely contends that one should begin with the least complex explanation possible and then elaborate upon it as required by the complexities of reality. Thus, the principle of parsimony is not intended to serve as a justification for reductionism. The second methodological assumption, the *principle of fallibilism*, assumes that error is possible in all human activity. Since scientific activity is a human activity, scientific knowledge production is also subject to error, and therefore should be subjected to criticism in the hope of producing ever better explanations of reality.

Semantic Assumptions

A key semantic assumption within science is the *correspondence principle*, which states that descriptions or explanations of phenomena generated by scientists are true to the degree that they correspond to reality (Mahner 2007). This semantic assumption is purely a connotative definition for the concept of truth, intended only to clarify what it means when scientists assert a knowledge claim about reality is *true*. The connotative definition of truth is not dichotomous, recognizing that the degree to which a knowledge claim corresponds to reality can vary. Thus, knowledge claims can be partially true, and measurements of the properties of phenomena can vary in terms of the precision or accuracy with which they represent reality.

Axiology/Moral Assumptions

Lastly, as a community of researchers, science assumes the presence of several institutional values, which include: logical, semantical, methodological, and attitudinal/moral values (Mahner 2007). These values are institutional in the sense that they are a property of the community of researchers, with individual scientists varying in the degree to which these values have been internalized. Logical values pertain to proscriptions against fallacious reasoning within knowledge claims, as well as prescriptions for internal consistency. Typical examples of fallacious reasoning include such things as: appeals to authority, consequence, and ignorance; tautological and teleological reasoning; and the fallacies of division and composition. Semantical values relate to the degree to which knowledge claims contain clearly defined concepts that can be clearly differentiated from other concepts within the same knowledge claim, as well as concepts present outside of the knowledge claim. The ambiguities present with a scientific field's knowledge claims can benefit the development of new scientific fields or hamper the development of established ones. Science also contains methodological values that emphasize: (1) the testability of assumptions, methods, and knowledge claims; (2) evaluative criteria for predictability, explanatory power, and the precision of descriptions or explanations of phenomena; (3) fecundity; and (4) the replicability of scientific studies. Lastly, values pertaining to the desirability of particular attitudes and/or morals are present within the scientific community. Within science, it is believed that scientists should be open-minded, exhibit objectivity, behave ethically, and think critically.

The Composition of Scientific Fields

Individual scientific fields are comprised of research communities who are professionalized and trained in specific ways and participate in field-specific traditions and practices in the production of scientific knowledge. Scientific fields can be distinguished from one another depending upon how fields vary in terms of their domains of discourse, primary aims, problematics, and the field-specific funds of knowledge they possess and produce (Mahner 2007).

Domain of Discourse, Primary Aims, and Problematics

A scientific field's domain of discourse, primary aims, and problematics vary depending upon whether a given field is a basic science, applied science, or technology (Mahner 2007). Table 1.2 contains a summary of these properties of scientific fields as they differ between these forms of science. The domain of discourse of any scientific field relates to the particular concrete phenomena being investigated, particularly in terms of its properties, generative causes, and changes over time. The domain of discourse for basic scientific fields includes the properties and causes of all things real that are observable through one's senses or technology, while applied scientific fields limit their domain of discourse to those things that are real and potentially useful. Because of their shared interest in reality, those engaging in basic and applied science are members of a broader community of scientists with whom they can interact and disseminate ideas. The domain of discourse of basic science is the broadest and most universal because it entails all the knowledge produced within all scientific fields, transcending disciplinary and even national boundaries. Applied science is more delimited in its domain of discourse because it is more narrowly focused on only those things that are of a potentially practical use. Technology, on the other hand, is only concerned with practical problems, and as a result produces processes and artifacts that are useful to only specific groups of people, regularly entailing specific sectors or industries. Because of intellectual property concerns, the domain of discourse for a process or item produced through technology can be further limited to those who are legally able to benefit from its uses.

The primary aims of science also differ depending on whether the scientific activities within a field are basic, applied, or technological in nature (Mahner 2007). The primary aims of basic science are purely cognitive and include the: disinterested pursuit of knowledge; discovery; application of scientific knowledge to produce new knowledge; systematization of theories or knowledge claims; and development and refinement of research

Table 1.2 Forms of Science: Basic Science, Applied Science, and Technology

	Basic Science	*Applied Science*	*Technology*
Aims	Purely cognitive. Discovery, systemization, and application of cumulative knowledge claims. Development and refinement of methodics.	Purely cognitive. Exploration of the possible pragmatic uses of cumulative knowledge claims.	Fabrication of processes or concrete things with practical uses. Efficiency. Provided by others. Do not engage in discovery, Content with existing knowledge.
Domain	Properties and changes of concrete things (things observable through senses or technologies). Relevant to general scientific community.	Properties and changes of concrete things (things observable through senses or technologies). Relevant to members of the scientific community who are interested in the possible practical uses of a phenomenon.	Practical problems. Only relevant to specific industries and sectors because applications are narrow and intellectual property concerns limit dissemination or use. Only concerned with use of engineered processes or concrete things.
Problematics	The questions scientists ask about reality. Solving problems that allow for discovery of cumulative knowledge claims.	The questions scientists ask about reality. Solving problems that allow for discovery of cumulative knowledge claims.	Practical implementation and feasibility. Problems of engineering. Dependence on science.
Activities	Novel empirical observation, theory confirmation, theory competition.	Novel empirical observation, theory confirmation.	Novel empirical observation

Source: Mahner (2007).

methodics that allow for future discoveries. The primary aims of applied science are much like those of basic science except for two key differences. One difference is that applied science focuses on studying phenomena that *possibly* have practical utility. A second difference is that applied science tends to be less concerned with the systemization of existing knowledge because of its narrower focus on the potential utility of phenomena. The motivational aims of technology fields are even further limited. Rather than focusing on the development of new knowledge, technology fields seek to apply existing knowledge directly toward the production of particular processes or material objects that are intended to increase the efficient and practical control of some phenomenon within a particular domain of activity. The particular process or item developed typically comes at the request of others, and the feasibility of actually generating the desired process or artifact often strongly influences its development. As such, the aims of technology are not purely cognitive. Instead, they are pragmatic.

The problematics of a scientific field directly relate to its domain of discourse and its various aims. Generally speaking, the problematics of a field pertain to the types of research questions it seeks to answer, as well as how it should proceed in answering them (Mahner 2007). Due to differences in the aims and domains of discourse between basic and applied science, significant differences also exist regarding the types of problems they encounter. Basic and applied science both possess problematics related to the asking and answering of questions about reality, albeit the questions of applied science are narrower due to its narrower domain. This entails not only developing knowledge claims that can explain phenomena, but also developing methodics that are capable of observing them. Technology, however, is concerned with issues of practicality or the feasibility—the problematics of engineering. Additionally, since technology is dependent on basic and applied science for the knowledge claims it uses, it is also dependent on their advances to produce ever more efficient products. Efficient solutions to problems must, therefore, regularly wait for basic and applied science to make discoveries.

These properties of scientific fields identified by Mahner (2007) can be further extended to apply to the numerous subfields that are typically located within any given scientific field. Scientific *subfields* are communities of scientific researchers embedded within a particular scientific field who focus on a narrower domain of discourse than that of the larger scientific field in which they are embedded. Due to their narrower focus, subfields encounter more specific problematics and produce a narrower subfield-specific fund of knowledge. Like scientific fields, subfields are also comprised of communities of interacting individuals that receive even more nuanced training and have their own unique traditions and practices that diverge from those present within the larger scientific field in which they are embedded.

Field-Specific Funds of Knowledge

The answers generated in response to a field's problematics form a scientific field's field-specific funds of knowledge, which includes all of the current theories, methodics, data, and facts used to explain phenomena located within a specific field (Mahner 2007). Field-specific funds of knowledge are shaped by the social organizational features of a given field in terms of its aims, domain of discourse, problematics, performance as a community, subfields located within it, and specific research programs.

The knowledge accumulated within scientific fields is generally one of two types: scientific facts and scientific knowledge claims or theories (Willer 1971; Willer and Willer 1972). The first kind of knowledge is a body of scientific facts about the empirical world, which might not be informed by scientific theories. When these facts are not explained by scientific knowledge claims, the purpose of science is to form abstract representations capable of explaining them. The second kind of knowledge is a stock of scientific knowledge claims. Broadly speaking, knowledge claims are declarations intended to assert an abstract 'truth' about a phenomenon (Steup 2014). Knowledge claims can make assertions about the properties of a single phenomenon, or they can also make assertions about how two or more phenomena relate to one another.[1]

The structure of scientific knowledge claims is primarily comprised of two dimensions. The first dimension, a formal one, specifies a knowledge claim's constituent parts—or in other words, the nuts and bolts comprising it. The second dimension is a substantive one and relates to whether knowledge claims are making statements about how to best *explain* phenomena or whether they are making statements about how to best *observe* them. The latter we refer to as methodic knowledge claims and the former we call theoretical knowledge claims. We further describe these dimensions of knowledge claims in the following section.

Formal Dimension

All scientific knowledge claims are comprised of concepts and propositions. A concept or *conceptual knowledge claim* is the most fundamental kind of knowledge claim within science, one asserting the very existence of a specific phenomenon with specific characteristics.[2] Generally speaking, concepts contain four parts. The first is a *label or name*, which functionally serves to differentiate one phenomenon from another symbolically. This label or name is accompanied by a second component, *a conceptual definition*, which specifies the unique characteristics that are possessed by all of the phenomena that share a common label. The third part is an *empirical definition* that specifies the procedures through which one translates an inherently abstract conceptual definition into something empirically observable and measurable. Lastly, the fourth part of a concept is the *referent*, which is the actual thing being recorded as data.

While concepts serve as knowledge claims that identify the existence of phenomena, scientists are also regularly interested in how two or more concepts relate to one another, usually when trying to explain the generative causes of a phenomenon. To explain the causes of a given phenomenon, scientists construct *propositions*, which are declarative statements that specify how one concept influences another[3] and under what conditions.[4] The combination of two or more propositions into a complex explanation of a phenomenon represents the combination of multiple propositions into a singular *model*. Models allow for more complex sets of causal statements than possible within a single proposition, such as positive or negative feedback loops, homeostatic regulation, or joint causality (see, e.g., Turner 1988; 1991).[5]

Substantive Dimension

The substantive dimension includes two sets of knowledge claims that are generated and employed by scientific fields. The first set of knowledge claims, methodic knowledge claims, pertain to what scientists typically refer to as research methods. The second set of knowledge claims are theoretical knowledge claims, or what scientists often call theories.

METHODIC KNOWLEDGE CLAIMS

There is a tendency within science to associate scientific knowledge claims with the theories or hypotheses generated by scientists to explain phenomena. This tendency, however, neglects that the procedures and technologies—or methodics—employed by scientists to study and observe phenomena make claims about the nature of reality as well. Generally speaking, methodics are the procedures and technologies—which can either be symbolic, as in a statistical model, or concrete, as in a survey instrument—used by scientists when empirically observing phenomena and testing knowledge claims (Mahner 2007).

The procedures and technologies contained within a field's stock of methodics function as knowledge claims in at least three ways. First, they state that the specific procedures or technologies being employed can observe a phenomenon reliably and validly. Second, they make statements about *why* specific procedures or technologies should result in reliable and valid observations. Lastly, they state *how* specific procedures and technologies work to produce valid and reliable observations.

Mahner (2007) identifies several characteristics of methodics that are scientific. These characteristics include: rule-directedness, theoretical justification, generality, objectivity, and scrutability. *Rule-directedness* refers to whether a methodic is systematically applied or is being applied in a willy-nilly or ad hoc manner. Longitudinal studies, for example, should not arbitrarily change the referents of concepts and then compare responses across periods when looking for trends. Instead, methodics should conform to specific sets of procedures when observing phenomena. *Theoretical justification* relates to the degree to which a methodic is based upon well-confirmed theoretical knowledge claims within scientific fields or the formal background knowledge of a field (e.g., logic or mathematics; we provide a discussion of formal background knowledge later within the chapter). The Tailored Design Survey Method (Dillman 2007), for example, utilizes social exchange theory for explaining why the method yields better response rates than other mail survey techniques. Additionally, methodics based upon random sampling draw from central limits theorem within statistics to justify the statistical inference of findings. *Generality* pertains to whether a methodic is suited for many kinds of investigations—both within and between scientific fields—or applies only to specific theories or problematics. *Objectivity* pertains to the degree to which similar results are produced when replicated by other competent scientists. A final characteristic of methodics, *scrutability*, refers to how transparent the previous characteristics are within a given methodic.

Based upon the particular constellation of these characteristics within a given methodic, we argue that a methodic can be categorized as either a divination/nascent methodic, a research technology, or a scientific instrument. If the type of information produced by a methodic is unclear, the particular procedures it employs are opaque, and the theory which explains why the methodic works is murky or absent, then we would say the methodic in question is nascent at best and unscientific at worst.[6] We use the term *divination/nascent methodics* pejoratively to describe methodics with these characteristics because there is no understanding of why the methodic yields specific observations, and yet it is afforded authority as if such an understanding exists.

A contemporary example of a divination/nascent methodic is the *Safe Range K II EMF Meter*, a very simple, inexpensive, and relatively unreliable electromagnetic field meter. When used correctly and as intended by the manufacturer, the *Safe Range Meter* detects the presence of an electromagnetic field, provides a reading of its strength, and the location of the field's source. However, according to many paranormal investigators, the meter is also capable of detecting the presence of ghosts and allowing ghosts to communicate with humans (Dickey 2016). Specifically, ghost hunters argue that the presence and movement of 'ghosts' cause fluctuations in the ambient environment, and these fluctuations are then detected by the meter. In fact, some paranormal investigators go as far as to say meter readings between 2 and 7 milligauss are 'proof' of ghost activity (Anomalies Research Society 2017). Of course, the ghost hunters' claims are not based on any scientific theory, nor are they grounded in any valid scientific methodologies—most of these explanations are arbitrary and ad hoc (ibid.)—and for this reason, they are divinations.

When the five dimensions characterizing an accurate methodic are present in an exemplary form, and the methodic has applications across many fields, a methodic can be said to be a *research technology*. Within the social sciences, survey methods represent a frequently utilized research technology. Lastly, *scientific instruments* are methodics that exist in an interstitial space, neither being divinations nor well-established research technologies. Scientific instruments might lack scrutability, or they can pertain to a very limited domain of research and contain high levels of scrutability.[7] For a similar discussion on methodics, see Baird (2004) and Joerges and Shinn (2000).

THEORETICAL KNOWLEDGE CLAIMS

Theoretical knowledge claims are the primary focus of any scientific field and include propositions or models that seek to explain phenomena within a scientific field's domains of discourse. As a fundamental aim of basic science is the systematization of knowledge, scientific fields and science as a whole seek to build a body of cumulative knowledge, which is a body of coherent theoretical knowledge claims that explain empirical phenomena (see, e.g., Collins 1986). Not all knowledge claims within science, however, have a cumulative and systematic character. For this reason, we distinguish between three types of theoretical knowledge claims: observational, substantiated, and cumulative knowledge claims.

Observational knowledge claims are the weakest form of theoretical knowledge claims, often representing a scientific researcher's first attempt at identifying, describing, or explaining a phenomenon's properties and/or generative origins. Observational knowledge claims draw their weakness from several sources. One source is that the phenomenon is not understood well enough to generate the kinds of concepts, propositions, and models needed to meet the axiological assumptions of science. Consequently, observational knowledge claims: (1) may contain concepts that are fuzzy; (2) might have propositions and models that are underspecified, including references to background and scope conditions; and (3) often lack clear connections to existing scientific stocks of knowledge. A second source of weakness is that the novelty of observational knowledge claims means that uncertainty exists surrounding the validity of the methodics used to develop them. This uncertainty begets several questions: If a new methodic was used, did it conform to the axiological/moral value of *rule-directedness*? If so little is known about a phenomenon, how can an existing methodic be *theoretically justified* in observing it? Following from these two questions, can other researchers follow the same methodic to yield similar *objective* results?

Because of these questions, observational knowledge claims are highly *tentative* statements about reality, claims that lack reliability and may contradict other scientific knowledge claims.

Given their high potential for error, observational knowledge claims are not yet substantiated knowledge claims. To become a substantiated knowledge claim, the axiological/moral assumptions of science (e.g., operationalization and replicability) require observational knowledge claims to be substantiated by others within the scientific community through a process commonly referred to as theory confirmation (Franklin 2007; Kincaid 1996). As a result of theory confirmation, observational knowledge claims are converted into substantiated knowledge claims insofar as they are empirically observed and not falsified by *other scientists*. Unlike observational knowledge claims, substantiated knowledge claims are *reliable* because other scientific researchers can reproduce them. Despite this reliability, substantiated knowledge claims may contradict existing scientific knowledge claims, and in doing so create paradoxes about reality. Since science contains the philosophical assumption of the principle of lawfulness, and paradoxes undermine the ordered nature of reality, the presence of competing substantiated knowledge claims that explain the same phenomenon creates apparent paradoxes within science that require resolution (see, e.g., Hacking [1983] 2010).

Cumulative knowledge claims are substantiated knowledge claims that have survived a more rigorous form of vetting within a scientific field known as theory competition. Theory competition occurs to resolve the paradoxes created when disparate observational or substantiated knowledge claims make contradictory statements about reality. When engaging in theory competition, scientists identify the empirical domain where substantiated knowledge claims are in contradiction and engage in an empirical observation, often referred to as a crucial test, to see which substantiated knowledge claim conformed with reality. Ideally, the substantiated knowledge claim that does not survive the crucial test is discarded or modified, and the one that does survive is retained and elevated to the status of a cumulative theoretical knowledge claim.

As a result of the theory confirmation and competition processes that they have undergone, cumulative knowledge claims have several characteristics. First, they are reliable in that other competent members of the scientific community can replicate them. Second, they are non-paradoxical in that they conform to reality and do not contradict other cumulative knowledge claims. Third, their high level of substantiation and lack of paradoxes means that they exhibit systemicity with theoretical knowledge claims in other scientific fields. Fourth, as a result of these characteristics, cumulative knowledge claims are marked by scientific consensus—a general agreement within a scientific field, as well as the overall scientific community—that a cumulative knowledge claim represents the best explanation of a phenomenon at a particular time. A final characteristic of cumulative knowledge, one also generated by the presence of the discussed characteristics, is that they allow for *encapsulated knowledge*. The encapsulation of knowledge occurs when highly detailed cumulative knowledge claims can be expressed in shorthand or packaged as turnkey solutions that allow others to take for granted their inner or underlying workings (see, e.g., Baird 2004).

In summary, a scientific field's field-specific fund of knowledge is comprised of the knowledge claims, data, and facts contained within a scientific field. The simplest form of knowledge claim is a concept—which contains a label, conceptual definition, operational definition, and empirical referent—that merely demarcates something as being unique from other things. Knowledge claims can also exist in the form of propositions or models that specify how two or more concepts relate to one another. Substantively, knowledge claims generally conform to one of two types. The first type, methodic knowledge claims, exist in the form of procedures and technologies that allow for the observation of phenomena. The second type, theoretical knowledge claims, seek to explain the occurrence of phenomena.

Research Programs

Within any scientific field, its field-specific funds of knowledge are generated within research programs that exist within the field's various subfields. Drawing from Mahner (2007), we define *research programs* as being a sequence of *research projects* that produce theoretical progress by allowing for the reinterpretation or modification of existing knowledge claims, where research projects are empirical assessments of a knowledge claim.[8] Insofar as a particular research project results in revisions of a knowledge claim that increases the predictive or explanatory power of it, the research program is seen as being theoretically progressive. Should a research project discover a new empirical fact, it is viewed as being empirically progressive. If a research project is both theoretically and empirically progressive, then the research program is considered progressive. Lastly, if a research project yields an outcome that is not progressive, then it is degenerative. Thus, for a research program to be seen as making progress, it must be both theoretically and empirically progressive.

A research program represents the lowest level of social organization within our hierarchy, the level in which scientific knowledge is actually produced. Research programs are much narrower in their domain of discourse, focusing on the empirical examination of single knowledge claim. As such, research programs encounter the problematics associated with actually conducting empirical tests—problems of implementation. Research programs are comprised of a small community of researchers, often including a single scholar and his or her research assistants or former students. As in higher levels of the hierarchy, this community entails the very close interaction of members and highly specialized training, which often occurs in the form of apprenticeships.

Formal and Specific Background Knowledge

In producing field-specific funds of knowledge, scientists are rarely completely isolated within their fields and research programs. If scientific knowledge were to be generated in such isolated conditions, every scientist would need to be frequently discovering knowledge that exists both within and outside of his or her field to be able to produce knowledge. Instead of operating in isolation, scientific fields are directly influenced by the field-specific funds of knowledge of adjacent scientific fields, as well as stocks of knowledge generated within mathematics and logic. Mahner (2007) refers to the field-specific funds of knowledge borrowed from other scientific fields as being a given field's *specific background knowledge* and the knowledge utilized within a field pertaining to mathematics and logic as being a field's *formal background knowledge*.

Specific Background Knowledge

The specific background knowledge of a given scientific field is comprised of the field-specific funds of knowledge located within neighboring scientific fields that are used in the production of its field-specific fund of knowledge (Mahner 2007). Neighboring scientific fields regular borrow theoretical knowledge claims from one another to promote better explanations of phenomena lying within their domains of discourse. Scientific fields also regularly borrow methodic knowledge claims when engaging in research projects, something possible because methodics are constructed in regard to problematics, which can be shared by a plurality of fields independent of the phenomena being studied. Psychology, sociology, criminology, and political science, for example, all seek to explain different domains of reality, but their common use of humans as a unit of analysis means that they encounter similar challenges when collecting data. Methodics relating to constructing a sampling frame, designing a survey instrument, and administering a survey instrument cannot be said to be owned by any one of these scientific fields.[9] Moreover, because of this quality of methodics, to the degree to which sets of problematics are widespread among many scientific fields, entire communities may arise whose sole focus is the development and refinement of methodics (see, e.g., Joerges and Shinn 2000).

The ability of distinct scientific fields to borrow field-specific funds of knowledge from each other is not merely a convenient way for scientific fields to develop knowledge: It is a crucial property of science referred to as *systemicity*. Systemicity pertains to the degree to which the domains of discourse and field-specific funds of knowledge within two or more scientific fields are intertwined in such a manner as to promote a convergent and unified understanding of reality (Mahner 2007). The presence of systemicity within a field is not simply a matter of one field's knowledge inspiring the knowledge produced in another field, but it instead pertains to the degree to which the theoretical or methodological knowledge claims produced within a field are directly incorporated into the theoretical or methodological knowledge claims of another field.

As a general property of science, several assumptions present within the philosophical orientations of science can be seen as promoting systemicity. The assumptions of ontological realism and the principle of lawfulness, in particular, assume there is only one ordered reality that can serve as the object of scientific inquiry. Consequently, although scientific fields may differ in terms of their domains of discourse, problematics, specific background knowledge, and field-specific funds of knowledge, science is nonetheless held together as a coherent epistemic field by its universal commitment to the ontological assumption of realism and the principle of lawfulness. Because of these assumptions, scientific fields seek to form a unified understanding of a highly complex reality that demonstrates systemicity, not a highly disciplinary or reductionist understanding of the world.

Formal Background Knowledge

The *formal background knowledge* utilized by scientific fields is comprised of current stocks of knowledge pertaining to formal logic and mathematics (Mahner 2007). As previously discussed, a core value within the scientific community is that theories should exhibit systemicity. Such a value presupposes the presence of a body of knowledge pertaining to logic, especially one that contains formal proofs justifying how and why the stock of logical knowledge works and should be considered valid. Rules of inference are regularly employed by scientists when crafting reasoned explanations of phenomena, even if only implicitly. Scientific research also relies heavily upon previously established mathematical proofs and statistical procedures developed within mathematics and statistics to produce scientific facts and carry out empirical observations. Most scientists, for example, are well versed in using statistical inference when evaluating hypotheses. Few scientists, however, likely know the formal proof of central limits theorem. The use of logic and mathematics within scientific fields is often taken for granted, as scientists are rarely also logicians or mathematicians. The activities of science would not be possible without these two forms of formal background knowledge.