5 Toward a Philosophy of Geomorphology

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ABSTRACT

Few attempts have been made to examine philosophically the scientific nature of geomorphology. The reluctance of geomorphologists to engage in philosophical analysis reflects, at least in part, a widespread skepticism of nonempirical forms of inquiry among practicing scientists. This perspective is an outgrowth of the a priori prescriptive nature of traditional philosophy of science. Contemporary philosophers of science have responded to the skepticism of practicing scientists by developing naturalized philosophies that illuminate the complexity of scientific inquiry through direct examination of scientific practice.

The objective of this chapter is to illustrate the potential for philosophical analysis to strengthen the intellectual foundation of geomorphology by providing insight into the scientific nature of the discipline. Several issues are introduced that have relevance for understanding geomorphology as a science, including classification, laws and causality, theory and models, discovery, gender issues, and applied studies. The discussion calls attention to unexamined aspects of these issues in geomorphology and briefly reviews contemporary perspectives on them in the philosophy of science. The purpose of the discussion is not to provide a penetrating philosophical investigation of each issue, but to establish an informative framework for future analysis.

INTRODUCTION

Geomorphologists generally have not exhibited much enthusiasm for engaging in philosophical introspection. Whereas the mention of theory commonly elicits the proverbial reaction of reaching for one's soil auger (Chorley 1978), the mention of philosophy is

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perhaps the surest way to get a geomorphologist into the field posthaste! The reasons for this aversion to philosophy are probably manifold (Rhoads and Thorn 1994), but no doubt it stems in part from an inherent skepticism about nonempirical forms of inquiry among practicing scientists. Philosophy often is largely ignored by scientists until a period of intradisciplinary dissension arises, whereupon forays into philosophy are conducted in an effort to provide external standards for resolving internal disputes (e.g. Sloep 1993). This book is partly the product of such a situation; it emerged in response to the recent spate of books and articles on philosophical and methodological issues in geomorphology (Douglas 1982; Starkel 1982; Church et al. 1985; Haines-Young and Petch 1986; Baker 1988, 1993; Ritter 1988; Thorn 1988; Brunsden 1990; Richards 1990, 1994; Baker and Twidale 1991; Montgomery 1991; Schumm 1991; Yatsu 1992; Rhoads and Thorn 1993, 1994; Bassett 1994; Rhoads 1994), which collectively suggest that the discipline currently is, if not in crisis, at least experiencing acute growing pains.

One reason why scientists in general, including geomorphologists, have viewed philosophy with a jaundiced eye is that traditional philosophy of science, particularly logical empiricism, has been highly normative or prescriptive in nature, a characteristic many scientists find annoying. No one likes to be told how to do their job better by someone who has not actually performed the tasks involved. This problem has been accentuated by the analytical nature of logical empiricism, which holds that the knowledge providing the basis for epistemic norms in science can be grasped a priori (i.e. through nonempirical reflection on the meaning of certain propositions). In other words, the philosophical program to understand science is independent of any specific scientific results, beliefs, or methods.

The nonempirical foundation of logical empiricism clearly conflicts with the empirical *modus operandi* of scientists. Contemporary philosophers of science fully recognize the need to grapple with this problem, and over the past 30 years (i.e. since the demise of logical empiricism) have focused their efforts on developing naturalized philosophical perspectives that attempt to capture the knowledge-producing potential of science as it is actually practiced. As noted by Shapere (1987, p. 10):

> Not only has traditional epistemology failed to provide the 'analyses' it promises; it turns out to have been misguided in principle in its methodological approach. For an understanding of the nature of knowledge - of the knowledge-seeking and knowledge-acquiring enterprise - can only be obtained through a study of the knowledge we have actually attained, of how we have attained it, and of how the goal of knowledge itself has been constructed and altered in that process.

Naturalized epistemology is largely descriptive or empirical, and in many ways constitutes a 'science of science'.

> Philosophy of science does not exist and function on a level above and independent of the substantive content of scientific beliefs; it is integrally and inseparably linked to that content, and its methods and conclusions must rest on the results of the very science with which it is concerned (Shapere 1987, p. 24).

This trait has led to criticisms that science is now being used to evaluate the knowledge claims of science, obviously a circular analysis, and that abandonment of a traditional role of philosophy, to provide an independent meta-narrative on science, threatens to obviate

Table 5.1. Main tasks of contemporary philosophy of science (after Shapere 1987)

Critical function
- Continue its traditional task of exposing confused or mistaken interpretations of science

Overview function
- Provide an overview of the rationale (or lack thereof) of scientific change
- Determine how specific beliefs develop and change
- Ascertain how certain beliefs are considered knowledge (i.e. are judged free from specific and compelling doubt
- Formulate conceptions of scientific reasoning and knowledge

Detailing function
- Conduct detailed studies of science, including case studies within specific disciplines, to determine how important presuppositions, beliefs, methods, criteria, goals, and so forth have developed and changed and to demonstrate important commonalities and differences among these factors across the various domains of science

philosophy of science (Trigg 1993). Debate about the extent to which science subsumes epistemology or epistemology subsumes science continues within the philosophy of science (Maffie 1990a, b, 1993; Axtell 1993), but many contemporary philosophers feel that by developing more accurate depictions of the ways in which science (or various branches of science) 'successfully' pursues certain types of goals, even the most extreme forms of naturalized epistemology can maintain a normative role in relation to science (Brown 1989).

A naturalized approach does not require that philosophy abandon its meta-narrative role in relation to science. Complete separation between philosophy and science is necessary only when one is attempting to avoid absolute skepticism about the possibility of scientific knowledge, not when one is interested in determining how particular processes within science produce certain *scientific* beliefs that are free from specific and compelling doubt (Shapere 1987; Nickles 1987). In this sense, naturalized philosophy still has important tasks to undertake in relation to science (Table 5.1).

What is the relevance of these developments in philosophy of science for geomorphology? Of course, the response to such a question ultimately must be a matter of opinion. Nevertheless, opinions will be based in part on whether persuasive reasons can be given for the value of a particular intellectual pursuit. The purposes of this chapter are to show how contemporary philosophical inquiry promises to illuminate the scientific nature of geomorphology and, in the process, contribute to the intellectual depth of the discipline. The discussion briefly identifies a broad range of important topics, each of which is deserving of penetrating analysis in the future. The intent is to provide another step forward toward a comprehensive philosophy of geomorphology.

DEFINITION OF GEOMORPHOLOGY

In preparing this book, a reviewer opined that a volume of this sort should provide a definitive definition of geomorphology. At first glance, such a request seems quite reasonable; should not a volume on the scientific nature of the discipline define geomorphology once and for all? Moreover, such a request does not seem to be too difficult to accommodate; one has simply to consult various introductory texts for cursory definitions that can provide the basis for a more elaborate definition (Table 5.2). Although some may be disappointed, such a definition will not be provided here. In keeping with naturalized approaches to the study of science, geomorphology is viewed as historically dynamic, having the potential to change character as it evolves through time. Although the discipline may eventually either cease to change or cease to exist, thereby either allowing for a stable definition or obviating the need for such a definition, the evolution of geomorphology cannot be determined a priori. All that can be done is to identify the current state of affairs and to speculate about the implications of emerging trends for the future of the discipline.

Textbook definitions of geomorphology have much in common and appear to be adequate for identifying the fundamental core, or *domain* (Shapere 1974), of contemporary geomorphology. These definitions suggest that few geomorphologists would disagree with the claim that the aim of the discipline is to investigate the surface forms and processes on the terrestrial portion of the earth. At present, inclusion of the morphology of the ocean floor or the study of the surfaces of other planets within the domain

Table 5.2. Definitions of geomorphology

- '...geomorphology is ... devoted to the explanation of the earth's surface relief and to an understanding of the processes which create and modify landforms' (Bridges 1990, p. vii)
- 'Geomorphology is the study of landforms, and in particular their nature, origin, processes of development and material composition' (Cooke and Doornkamp 1990, p. 1)
- 'Geomorphology is the study of the surface of the Earth. Classically, geomorphologists have studied landforms, which are shapes that have been categorized or named by geomorphologists or other Earth scientists' (Mayer 1990, p. 1)
- 'Geomorphology ... is the scientific study of the geometric features of the earth's surface. Although the term is commonly restricted to those landforms that have developed at or above sea level, geomorphology includes all aspects of the interface between the solid earth, the hydrosphere and the atmosphere. Therefore, not only are the landforms of the continents and their margins of concern, but also the morphology of the sea floor. In addition, the close look at the moon, Mars and other planets provided by spacecraft has created an extraterrestrial aspect to geomorphology' (Chorley et al. 1984, p. 1)
- 'Geomorphology is best and most simply defined as the study of landforms. Like most simplistic definitions, the actual meaning is somewhat vague and open to interpretation' (Ritter et al. 1995, p. 3)
- 'Geomorphology is the study of the origin and evolution of topographic features by physical and chemical processes operating at or near the earth's surface.... the study of surface processes and landforms relies heavily on geologic principles. Yet, like other sciences, geomorphology also depends on the application of basic principles of physics, chemistry, biology, and mathematics to natural systems' (Easterbrook 1993, p. 2)
- '*Structures*, *materials*, *processes*, and the *history* of changing landforms, are the four essential components of a study of the nature and origin of the modern land surface...' (Selby 1985, p. 1)
- ' . . . the systematic description, analysis, and understanding of landscapes and the processes that change them ... the description, analysis, and understanding of landforms...' (Bloom 1991, p. 1)
- 'Geomorphology is the science concerned with the form of the landsurface and the processes which create it. It is extended by some to include the study of submarine features, and with the advent of planetary exploration must now incorporate the landscapes of the major solid bodies of the Solar System. One focus for geomorphic research is the relationship between landforms and the processes currently acting on them' (Summerfield 1991, p. 3)
- '. . . geomorphology is broadly defined as the study of past, present, and future landforms, landform assemblages (physical landscapes), and surficial processes on the earth and other planets' (Rhoads and Thorn 1993, p. 288)

of geomorphology may be more hopeful than well-founded. Few scientists that study deep ocean basins or the surfaces of planets such as Jupiter or Saturn probably consider themselves geomorphologists. One might qualify the extended definition by restricting it to near-coastal submarine forms or to the surfaces of solid planets, but this type of restriction begins a slide down the slippery slope of additional qualifications (e.g.- solid planets with atmospheres similar to the Earth's atmosphere). In the end, this problem merely points out that whereas a core of geomorphology can be identified, its periphery is rather fuzzy, a trait that characterizes many fields of knowledge (Shapere 1974).

NATURAL KINDS

One way in which philosophical analysis can contribute to geomorphology is to help unify the discipline by identifying bases for common ground among a diverse group of scientists all of whom consider themselves geomorphologists. Whereas some geomorphologists have viewed methodology as a potential unifier (Haines-Young and Petch 1986; Richards 1990, 1994), Rhoads and Thorn (1993, 1994) have argued that methodology is a healthy source of diversity, rather than unity in the discipline. The chapters in this volume reinforce this perspective and also highlight the contributions that diverse methodologies have made to geomorphological knowledge. This situation suggests that any sense of disciplinary unity is best achieved by focusing on some aspect of geomorphologic inquiry *other than* methods of inquiry. An obvious alternative is the objects of inquiry.

An important component of any science, including geomorphology, is classification. Geomorphologists have approached the study of the Earth's surface by classifying it into discrete categories, or taxa, known as landforms. The ubiquitous reference to landforms in definitions of geomorphology (Table 5.2) clearly demonstrates the centrality of this concept in the discipline. Landforms provide the basis for process and geohistorical investigations of the Earth's surface. In turn, landform taxonomy often is refined based on the results of such investigations. An example is recent work in fluvial geomorphology, which has identified anastomosing and wandering gravel-bed rivers as distinct types that differ fundamentally from meandering, braided, or straight rivers (Church 1983; Knighton and Nanson 1993).

The centrality of the concept of 'landform' in geomorphology raises several important epistemological and metaphysical issues that have not been adequately addressed by geomorphologists. Despite the frequent mention of landforms in definitions of geomorphology, none of these definitions specifies what a landform is. Only Mayer (1990) addresses this issue directly and his explication is largely unhelpful. Because the concept of 'landform' underpins geomorphologic classification, which in turn provides the basis for much geomorphologic inquiry, it is important to consider the metaphysical nature and epistemic utility of this concept. In particular, geomorphologists have not adequately grappled with questions such as: How is 'landform' to be defined in geomorphological taxonomy? What is the epistemic purpose of landform classification? What standards or criteria provide the basis for defining types of landforms? Are these standards or criteria consistent with the epistemic purpose of classification? Does landform classification have an objective basis in nature or is it merely an artifact of human comprehension? Answers to these questions are important because they can help clarify whether the epistemic basis of geomorphological classification is consistent with the overall epistemic goals of geomorphological inquiry and whether the science of geomorphology can be justified on ontological grounds.

Philosophical analysis of scientific classification has centered on the problem of natural kinds. The pivotal idea behind the concept of natural kinds is that individual objects in the world are naturally divided into distinct classes, or *kinds* of entities by virtue of certain shared intrinsic properties. Natural kinds define the basic types of objects that exist in the world. Categories that do not have an objective basis in nature, but that have been developed for human purposes only, are artificial or nominal kinds (Schwartz 1980). The notion that a goal of science is to discover natural kinds and develop scientific explanations for the existence of these kinds constitutes an implicit, widely held conviction among practicing scientists. The search for natural kinds can be viewed as epistemologically privileged in relation to other types of human inquiry because it represents an attempt to uncover the true way in which the world is structured independently of human thought. It represents an attempt to 'carve the world at its joints'. Natural kinds are fundamental in science because they serve as the foci of theoretical generalizations (e.g. Rothbart 1993).

The concept of natural kinds has a long and controversial history within the philosophy of science (Hacking 1991), dating to Aristotle (Granger 1989; Suppe 1989, pp. 204-205). Arguments for and against the concept have been best developed for biology, especially with regard to whether or not species constitute natural kinds (e.g. Kitts and Kitts 1979; Dupre 1981, 1989, 1994; Fales 1982; Kitcher 1984; Ruse 1987; Wilkerson 1988, 1993; Stanford 1995), but the concept has also been applied in physics (Quine 1992), chemistry (van Brakel 1986), and even economics (Nelson 1990). Much debate has centered around the basis on which natural kinds should be identified (cf. Quine 1969). Perhaps the most controversial aspect of contemporary philosophical debate about natural kinds is the notion that any object belongs to an unambiguously discoverable natural kind on the basis of a certain essential (necessary and sufficient) property or set of properties. Often the properties that determine the real 'essence' of a kind are viewed as underlying causal mechanisms, powers, or processes (e.g. the molecular structure of water (Putnam 1975) or the genetic structure of living organisms (Wilkerson 1988)). The implication of such a view is that any object belongs to a natural category *independent of the context of inquiry,* that this category is determined by some shared 'real' essence among certain objects, and that it is the goal of science to discover these 'hidden' or 'theoretical' real essences, thereby revealing the true structure of the natural world. Such a view, with its emphasis on 'hidden', 'internal', 'microscopic' causal powers has metaphysical connotations, providing the basis for many realist perspectives on science (Boyd 1991). It also has reductionist implications for scientific inquiry (Meyer 1989). For example, if relations among microscopic physical particulars constitute the real essences (causal mechanisms) of macroscopic phenomena (i.e. these relations determine the macroscopic properties of macroscopic phenomena), then all generalizations about macroscopic phenomena can be at least quasi-reduced to fundamental physics because the structure and function of macroscopic phenomena are ontologically (and possibly epistemically) quasi-reducible to microscopic physical entities and causal relations (e.g. Melnyk 1995).

Not all philosophers agree that natural kinds are determined by essential, underlying causal powers or mechanisms. Many hold that the definition of a natural category, even one that is theoretically based, depends on the context of inquiry (De Sousa 1984; van Brakel 1992; Dupre 1993; Shain 1993), or that the concept of essentialism, as outlined by its proponents (e.g. Putnam 1975; Kripke 1980; Leplin 1988), cannot be sustained when examined philosophically or within the context of actual scientific practice (Mellor 1977; Nersessian 1991; Shapere 1991; Stroll 1991; Li 1993). The challenge posed by context-dependent kinds is that such a view threatens to undermine the epistemically privileged status of scientific inquiry (i.e. the search for the 'essential' set of natural kinds that exist in the world).

Are landforms natural kinds? It is beyond the scope of this chapter to analyze this question in detail. However, future analysis of the question may be fruitful given the centrality of classification in geomorphology. Such analysis may yield insights about the epistemological role of classification in the discipline and whether or not such classification is merely epistemically convenient (as argued for geology by Watson 1966) or has a justifiable ontological basis. A starting point for addressing this question would be to determine whether specific types of landforms are fixed by a necessary and sufficient property or set of properties. Morphologic properties alone cannot provide necessary and sufficient conditions because these properties vary in detail among individual landforms of the same type. Moreover, the concept of equifinality suggests that similar morphologic properties can be produced by different causal mechanisms, calling into question (at least from an essentialist perspective) the appropriateness of existing landform categories. A possible solution could be to revise existing categories based on reductionist analyses of underlying mechanisms, but such an endeavor could have important implications for the ontological status of landforms. For example, Wilkerson (1988), a leading advocate of essentialism (and thus realism), argues that geological and geographical kinds (e.g. cliffs, beaches, mountains, valleys, volcanoes, rivers, glaciers) do not have real essences and thus are unlikely to yield theoretical generalizations, a claim that may be difficult to refute given the current status of theory development in geomorphology. To Wilkerson, these features are 'superficial' kinds, not natural kinds. Scientific inquiry in fields such as geology or geography is possible only because the superficial kinds of interest are composed of physical and chemical constituents (i.e. natural kinds) that do have real essences. Such a view does not exclude an epistemic role for geomorphology (i.e. to uncover underlying relations among physical/chemical kinds responsible for similarities among superficial properties of the landscape that lead us to classify it into landforms), but it does sharply reinforce the popular, implicit ideology that geomorphology is nothing more than applied physics and chemistry (because landforms have no ontological status apart from their physical/chemical constituents and properties). Such a perspective stands in stark contrast to Dupre's (1993) claim that the conventionality of classification at all levels of scientific inquiry undermines essentialism and reductionism, and supports a form of ontological pluralism he calls promiscuous realism.

The problem of natural kinds also raises the issue of whether classification of the physical landscape into categories known as landforms is a nominalistic exercise that is providing a misleading theoretical picture about the 'real' structure of the landscape. When classification is applied to a landscape (as in geomorphological mapping), it requires the imposition of boundaries, boundaries that often are useful from a practical or methodological perspective, but that may not exist in nature. Gould (1987, pp. 160-161) argues that although discrete 'islands of form' can sometimes be identified in nature, 'we must accept shadings and continua as fundamental'. This alternative perspective on the natural world provides ontological and epistemological support for holistic landscape analyses that treat planetary surfaces as continua (e.g. fractal analyses of planetary terrains; phy-sically based models based on continuum concepts), rather than as assemblages of individual landforms. On the other hand, sophisticated conceptions of natural kinds recognize and attempt to accommodate intraclass variation and indistinct boundaries between natural categories (Boyd 1989; Suppe 1989). Under these conceptions, the 'essence' of the kind (with the kind being characterized by a variable but clustered set of properties) will consist in the complete catalogue of laws or causal mechanisms respon-sible for the clustering of properties. In any case, a naturalized view of geomorphology maintains that philosophical arguments for or against the existence of natural geomor-phologic kinds will be adjudicated over the long term by the relative empirical adequacy and explanatory power of geomorphological theories that posit the existence of such kinds versus those that do not.

LAWS, CAUSALITY, AND CAUSAL EXPLANATION

Geomorphology is a science that deals with complex, dynamic natural systems consisting of physical, chemical, and biological constituents and attributes. The questions arise whether it is possible for sciences of this type to develop their own laws and if such sciences can successfully employ laws of the basic sciences to explain (and possibly predict) the natural phenomena with which they are concerned. In part, the answers to these questions depend on how one defines the concept of law and the role that one assigns to laws in scientific explanation.

According to the logical empiricist conception, laws of nature express empirical regularities. As noted by Carnap (1966, p. 3) 'if a certain regularity is observed at all times and all places, without exception, then the regularity is expressed in the form of a "universal law"'. This perspective implies that the cognitive content of a law consists in a predicted pattern of perceptual observations and that the evidence for a law consists in a set of observations that instantiate this pattern (Boyd 1985). Of course, logical empiricists recognized that not all empirical regularities constitute laws, but in keeping with the empiricist aversion to metaphysical commitment, they approached this issue as a linguistic problem about laws as *universal statements.* In other words, distinguishing law-like generalizations from accidental generalizations should be based on the syntactic properties of particular statements expressing these generalizations (cf. Lambert and Brittan 1970, pp. 37-45).

Geomorphologists, like most scientists, are greatly concerned with explaining the natural phenomena they study. The concept of explanation is itself deserving of further exploration, but many practicing scientists value greatly *causal* explanations, or those that identify causes of empirical phenomena (Dilworth 1994; Barnes 1995). The empiricist conception of causal explanation, the covering-law model, is derivative from the view of laws as regularities:

> The type of explanation which has been considered here so far is often referred to as causal explanation. If E describes a particular event, then the antecedent circumstances described in the sentences C_1, C_2, ... C_k may be said jointly to 'cause' that event, in the sense that there are certain empirical regularities, expressed by the laws L_1, L_2.... L_r, which imply that whenever conditions of the kind indicated by C_1, C_2, - - -, C_k occur, an event of the kind described in E will take place. Statements such as L_1, L_2, ... , L_r which assert general and unexceptional connections between specified characteristics of events, are customarily called causal, or deterministic, laws (Hempel and Oppenheim 1948, p. 139).

The covering-law model associates causal explanation with subsumption of an event to be explained (E) under deterministic laws, where deterministic refers to exceptionless generalizations. It is clearly an attempt to analyze causal relations in terms of laws. However, because the empiricist concept of a law consists in nothing more than reference to regular patterns in observable data, the covering-law model of causal explanation does not permit a metaphysical interpretation. In other words, it implies that *causation consists in nothing more than regularities in the behavior of observables.* This strategy represents an attempt to reduce the concept of causation to an empirical interpretation (Tooley 1990) - laws are merely summaries of what is observed (Boyd 1985). Such a perspective opposes the intuitive understanding of causation as involving a precipitating event, a resulting event, and a *causal process that connects the two events by propagating a causal influence from one space-time locale to another* (Salmon 1984, p. 155).

The empiricist conception of laws is highly controversial. Realist philosophers have challenged this conception by attempting to provide laws with an ontological status. These alternative conceptions are worth examining given the recent concern about realism in geomorphology (Richards 1990, 1994; Bassett 1994; Rhoads 1994). Realist views on laws consist of two types of claims: (1) that laws describe *necessary relations* between universal properties associated with certain objects (e.g. Dretske 1977; Armstrong 1983; Tooley 1987), and (2) that laws describe manifestations of *causal powers, capacities, or dispositions* possessed by certain objects or classes of objects (Cartwright 1989; Bigelow et al. 1992; Woodward 1992). The difference between these two positions is subtle but important. The first treats laws as universals, i.e. relations that exist separately from objects and govern regular behavior among objects. These universals are treated as irreducible primitives whose ontological status is unanalyzable and simply must be accepted. The second conception does not assign an independent existence to laws; instead laws derive from the capacities of kinds of objects to effect change. The difference between the two conceptions can be captured by an analogy to a chess game. In the first case, laws represent rules that govern the movements of specific types of pieces; these rules exist independently of the board and pieces in the form of a rule book. Thus, if the rule book was written differently (i.e. allowing rooks to move diagonally), the types of pieces could and would move differently. According to the second view, the rules (laws) arise from the capacity of the types of pieces themselves to move only in specific patterns. The rules are what they are because of the capacities of the types of pieces; the rules are prescribed by these capacities and are not a contingent matter. In other words, causal capacities are fundamental relative to natural laws.

One implication of the view that laws ensue from causal capacities is that the concepts of causation and causal law can be divorced from the concept of regularity (Cartwright 1989; Woodward 1992). The causal capacities of particular kinds of objects may manifest themselves differently (i.e. produce different outcomes) depending on the specific context in which the cause operates. Ascriptions of capacities define the range of possible outcomes a kind of object can cause, but are too general to be used for precise predictions. Causal lawfulness, on the other hand, is based on the criterion of *invariance of causal relations,* rather than solely on regularities in empirical data (Woodward 1992). Invariance refers to functional stability of a causal relation as initial conditions change over a specified range in a constrained setting. Because causal laws define causal relations that obtain *in specific situations,* they can be used for prediction. The need to specify the circumstances within which a particular causal relation obtains, however, implies that all causal laws are *ceteris paribus* generalizations (Lange 1993; Cartwright 1995). The manifestation of causal capacities in complex systems, such as those studied in geomorphology, will vary, depending on the nature of interactions among various capacities within a specific context. Regularities will emerge only when a capacity or set of interacting capacities is triggered repeatedly within uniform settings (i.e. those that appropriately shield the capacity from interacting with specific features of a new situation). Thus, the study of complex phenomena poses a problem both for inductively establishing the existence of underlying causal laws based on regularity principles and for identifying possible combinations of underlying causal laws by combining mathematical formulations of these laws in predictive models. This situation may account for the fact that geomorphology has not been very successfull at developing its own laws, or in using simple models that combine a few basic physical laws to predict the form and dynamics of specific landforms - a topic which has received considerable attention elsewhere in this volume. It also points out the need both for detailed experimental work, in the field and in the lab, and for large-sample investigations (e.g. Richards, Chapter 7 this volume). In experimental work, specific conditions can either be created artificially or at least precisely documented so that particular manifestations of causal capacities can be deduced from data or specific claims derived from causal laws can be evaluated from patterns of data (Peakall et al., Chapter 9 this volume). On the other hand, large-sample investigations are useful for isolating statistically causal capacities that operate irregularly within uniform settings (and thus underlie probabilistic causal laws) or that operate regularly, but whose effects are readily confounded by interaction with other causal capacities in nonuniform settings (Woodward 1992; Dupre 1993, pp. 194-217).

Another challenge to the empiricist account of laws comes from the realm of nonlinear dynamics, a topic that is beginning to have an impact on geomorphology (Phillips, Chapter 13 this volume). Sensitive dependence of outcomes on initial conditions greatly complicates efforts to inductively derive or test the functional form of an underlying nonlinear law based on regularities in patterns of data, especially for complex natural systems in which initial conditions are likely to exhibit considerable variability (Holt and Holt 1993). This empirical problem is also in part a problem for the realist account of laws, but, by embracing the evidential role of accepted background knowledge on causal capacities, which is held to be at least approximately true, the realist has additional epistemic resources for evaluating the validity of competing theoretical models, all of which may be 'equifinal' in the sense of having similar predictive accuracy (e.g. Beven, Chapter 12 this volume). To the realist, the evaluation of a theoretical model is based not only on empirical adequacy, but also on how well the model is grounded in accepted background knowledge. To take full advantage of these additional epistemic resources, nonlinear geomorphological models should be explicitly and unambiguously linked to known causal mechanisms. However, at present, many nonlinear models in geomor-phology are based on simple mathematical functions (ordinary differential equations) that include aggregated variables, each of which may subsume a complex amalgamation of physical, chemical, or biological mechanisms. Thus, qualitative stability analysis of such models cannot yield explanations that specify the role that underlying mechanisms play in system response; instead, one must assume that the aggregated variables can effect change in the manner specified by the structure and functional form of the equations. In this sense, many nonlinear models, like multivariate statistical models, are 'black box' models.

An obvious question is: can philosophical discussion about the nature of laws be adjudicated in any way by an analysis of scientific practice? The answer is - to some extent. The logical empiricist perspective in large part arose from the fact that theoretical laws in physics often do not specify causes: 'the reason why physics has ceased to look for causes is that, in fact, there are no such things' (Russell 1917, p. 174). However, more recent examinations of physics (Cartwright 1981, 1983) and other areas of science (Cartwright 1989) seem to indicate that the empiricist claim that scientists have a greater epistemic commitment to laws than to causes is flawed. Not only do scientists attempt to identify causes, but they often treat ascriptions of causal capacities as more fundamental than theoretical laws. Whether or not geomorphologists conform with this assessment will not be considered here, but recent concern about the search for causal mechanisms in geomorphology (e.g. Richards, Chapter 7 this volume) suggests that this issue at least is worthy of further exploration. A concern with the nature of laws and causal explanation is important in geomorphology because it is intimately linked to scale-related issues, especially the potential for the character of geomorphological methods and explanations to vary over the temporal and spatial range of inquiry (e.g. Rhoads and Thorn 1993; Church, Chapter 6 this volume). The recent trend toward reductionist analyses based on the principles of mechanics may be motivated not only by pragmatic problems related to the development of empirical laws for complex, evolving natural systems (e.g. van der Steen and Kamminga 1991), but by a fundamental concern about the causal relevance of macrolevel phenomena - a worry generated by proponents of reductionism (e.g. Kim 1989). The widespread adoption of mechanics in geomorphology suggests that causal powers may lie in physical entities such as forces (e.g. Tuchanska 1992; Cartwright 1995), but geomorphologists should be cautioned that the ontology of forces and other entities that populate physics is far from clear (Bigelow et al. 1988; Jones 1991). On the other hand, those geomorphologists with an antireductionist bent (e.g. Haff, Chapter 14 this volume) may find solace in recent philosophical work on macrolevel causation (e.g. Henderson 1994) and on the value of case studies for deriving and evaluating causal explanations about complex, seemingly unique phenomena (Shrader-Frechette 1994). In any case, the problems of the existence, relevance, and spatial-temporal variation of causal agents in geomorphology are a posteriori theoretical issues that can only be adjudicated on the basis of how various theory-directed research programs fare in competition with one another. Realists will view such evolution, should it occur, as the triumph of truth over falsity (e.g. Richards 1990), relativists will see it as the triumph of particular research styles (Vicedo 1995; Osterkamp and Hupp, Chapter 17 this volume) or fashions (Sherman, Chapter 4 this volume), pragmatists will hail it as the triumph of practical utility and societal relevance (Baker 1994), and empiricists will proclaim it as the triumph of empirical adequacy (Beven, Chapter 12 this volume).

THEORY AND MODELS

Theory is a central concept in science. Most scientific activity centers around the development and testing of theory. Given that geomorphologists generally consider their discipline a science, it is not surprising that they have expressed an interest in the role of theory in geomorphology (Baker and Twidale 1991; Rhoads and Thorn 1993). Contemporary philosophical analysis suggests that theories are not merely storehouses for scientific knowledge, but that they also have a pervasive methodological influence on scientific inquiry (Brown, Chapter 1 this volume). Most observational procedures are now viewed as theory-dependent (at least to some extent) - a perspective that appears to apply to geomorphology (Rhoads and Thorn, Chapter 2 this volume). More analysis is required to determine the extent to which methodological procedures are infused with theory in geomorphology and to examine the epistemological implications of the relationship between theory and observation in specific instances.

Another type of philosophical investigation that may prove fruitful is formal analysis of the structure of geomorphological theories. The concept of a theory is certainly a fuzzy one within the philosophy of science, within science in general, and within geomorphology in particular. A continuum of perspectives on theory has emerged from the philosophy of science, ranging from the simple notion of a theory as a hypothetical claim with empirical content (Popper 1965, p. 115) to the sophisticated, logical-analytic view of theories as axiomatized, hierarchical systems of deductively connected statements (Feigl 1970). Most scientists, including earth scientists, tend to make an implicit distinction between hypotheses and theories. In general, a theory is viewed as more comprehensive and reliable than a hypothesis (von Engelhardt and Zimmermann 1988, p. 234). Similarly, philosophers interested in formal analysis of theory structure usually examine theories that consist of more than a singular hypothetical claim.

The view of theories as axiomatized systems of statements is commonly referred to as the Received View. Many geomorphologists may be familiar with the basic tenets of the Received View through their training in geography (Harvey 1969; Amedeo and Golledge 1975) or geology (Kitts 1963; von Engelhardt and Zimmermann 1988). This perspective emerged from logical empiricism and incorporates many of its basic tenets, including the observational/theoretical distinction, knowledge empiricism, and the verifiability theory of meaning (Rhoads and Thorn 1994). It is beyond the scope of this chapter to review in detail the Received View (for comprehensive overviews see Suppe 1977a, pp. 6-61 and 1989, pp. 39-62). The important point here is that this view has never been popular among scientists given that its main focus is to provide an artificial reconstruction of existing theories within an explicitly characterized formal language, rather than to provide an accurate depiction of how scientists actually construct and use theories (Feigl 1970). In particular, the emphasis on theories as linguistic entities fails to adequately capture the pervasive use of models in science.

Over the past 30 years, considerable effort has been devoted to an alternative to the Received View known as the Semantic or Model-Theoretic View (MTV) of theories (Suppe 1977a, pp. 221-230, also 1989; van Fraassen 1980, pp. 41-69, also 1987; Giere 1988, pp. 62-91). According to MTV, a theory is specified by defining a family of abstract struc-tures, i.e. its models. Because models are nonlinguistic entities, they can be characterized in many ways using many different languages. In other words, although an expression of a theory may include statements in a specific language (including equations), the use of this language is not fundamental because the same class of models could be described in other languages as well. Specification of a class of models involves theoretical definitions that draw upon the laws or postulates of the theory (Giere 1979, pp. 63-83). Thus, the relation between the models and the underlying theory is unproblematic; the models are, by definition, true representations of the theory. However, the goal of scientific inquiry is not to study relations between theories and their models, but to examine relations between theories and some real-world phenomena (i.e. the intended scope of the theory). The link between the models, or idealized abstract systems representing the theory, and some identified class of real phenomena is achieved by specifying theoretical hypotheses. These linguistic statements make claims about the world in relation to the model, usually of the type that the phenomena would be as the model prescribes if all of the idealized conditions specified in the model had actually obtained. One implication of this view is that the evaluation of hypotheses is not performed by comparing statements about phenomena with direct observations (sensory perceptions) of phenomena, but rather by comparing theoretical hypotheses with data about phenomena (Figure 5. 1). The production of data draws upon various types of auxiliary theories, including those governing data collection

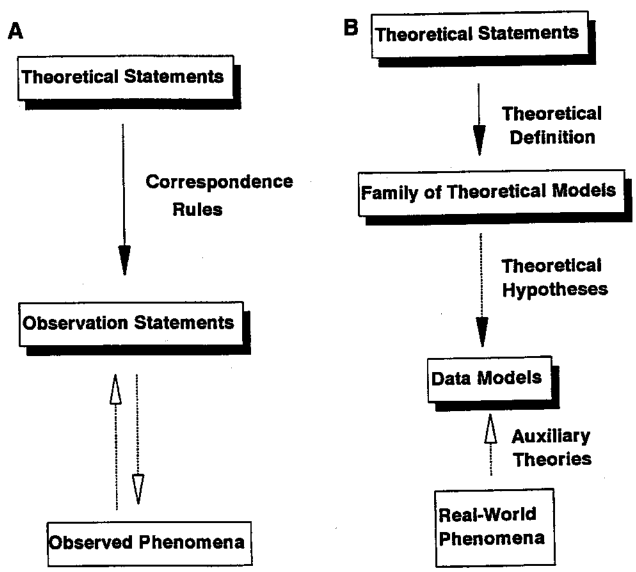

Figure 5.1. Contrasting philosophical perspectives on the structure of scientific theories: (A) the Received View. Theoretical statements are connected to observational statements via correspondence rules (explicit or partial definitions). Observational statements are directly testable (verified or refuted) by comparing these statements with observations. (B) The Model-Theoretic View. Basic theoretical statements define families of theoretical models that represent abstract, idealized representations of some domain of real-world phenomena. Raw data on real-world phenomena along with auxiliary theories governing data reduction and analysis are used to develop data models, which provide the basis for evaluating theoretical hypotheses that individually make claims about the real-world system being a system of the type defined by the theory

(experimental design, instrumentation, selection of certain types of information as opposed to others), data reduction and analysis (statistics, processing routines, presentation methods), and data interpretation (inferences about extant patterns and their relation to attributes of underlying phenomena). The outcome of this process is the construction of a data model. The purpose of creating a data model is to ensure compatibility between the data gathered from the real world and the form of information specified by the theoretical model. In other words, a theoretical model specifies the pattern of data a phenomenon or set of phenomena should generate under a particular set of idealized conditions, and the data model reveals whether this pattern of data is, in fact, present in the data collected from the real-world system.

The advantages of MTV are several. First, in characterizing theory, it puts models, rather than hierarchical systems of statements expressed in a formal language, on center stage - a portrayal of theory that accords well with actual scientific practice. The large number of chapters on models and modeling in this volume suggests that geomorphology conforms at least to some extent with this characterization. Second, MTV, by emphasizing the nonlinguistic, abstract nature of theories, easily accommodates the notion that theories are conceptual devices (Suppe 1977b, pp. 706-716) or mental representations (Giere 1992, 1994) that can be expressed mathematically, qualitatively, or iconically (e.g. Da Costa and French 1990). This aspect of MTV holds promise for geomorphology, which includes qualitative conceptual models as well as various types of quantitative models. Also, the implication that, as idealizations, theories always fall short of completely capturing the full complexity of real-world phenomena should appeal to geomorphologists who believe that the greatest asset of theory is its fallibility, i.e. its role in highlighting anomalous data and in promoting the search for new theories. The search for phenomena through the development of data models can serve as the impetus for theory change as new phenomena are revealed that cannot be accommodated by any possible model of an accepted theory (van Fraassen 1987). Third, MTV emphasizes that the relation between theoretical propositions and the real world is not direct, as implied by the Received View, but instead is mediated through abstract idealizations, i.e. models (Figure 5.1). Current attempts to apply physical theory to geomorphic phenomena appear to be broadly consistent with this perspective. The general hypothesis that a particular feature of the landscape is a type of natural mechanical system is not evaluated by attempting to assess directly basic propositions from classical mechanics (e.g. Newton's Laws of Motion); instead, the validity of this general hypothesis is assessed by formulating a class of models (expressed mathematically) and testing specific claims about the relation of the predictions of a particular model to data on real-world phenomena. Fourth, MTV stresses the important role of hypotheses in science. This aspect should have an intuitive appeal for geomorphologists, who traditionally have embraced hypotheses and hypothesizing as an important component of geomorphologic inquiry (Schumm 1991; Baker, Chapter 3 this volume). Fifth, MTV has been applied to the formalization of theories not only in physics and chemistry (Suppe 1989), but also in biology (Thompson 1983; Beatty 1987; Lloyd 1989; Sintonin 1991), a discipline which, like geomorphology, is characterized by qualitative and quantitative models that are based on a mixture of principles from within the discipline and from other disciplines. One particularly promising application of MTV in biology suggests that it can accommodate seemingly nonuniversal theories characterized by *ceteris paribus* conditions that include entities at different levels of aggregation (i.e.

different scales) (Schaffner 1980). Such versatility is probably essential for efforts to formalize geomorphologic theories, given the centrality of environmental contingency and scale issues in geomorphological explanations.

DISCOVERY

A criticism of philosophy of science frequently specified by scientists, including geomorphologists (Baker and Twidale 1991), is that most philosophical analysis focuses on justification, rather than on discovery of scientific knowledge, even though the latter, rather than the former, is the most vital dimension of science. Such perceptions reflect the pervasive influence that logical empiricism, with its distinction between the contexts of discovery and justification (e.g. Reichenbach 1938), has had on scientists' views of the philosophy of science. In contrast, nineteenth-century philosophers of science, such as John Herschel, William Whewell, and Charles Peirce, devoted considerable attention to the problem of scientific discovery, especially with regard to the problem of how hypotheses are formulated and evaluated, a topic of special interest in geomorphology (Baker, Chapter 3 this volume). Hanson (1958) and Kuhn (1970) initiated a renewed interest in the problem of discovery and the literature on this topic has increased rapidly over the past 25 years in conjunction with the emergence of postpositivist interpretations of science (Nickles 1980, 1985, 1990; Kelly 1987; Lai 1989; Kantorovich 1993).

Discovery in science generally involves at least one of the following: (1) the invention of new, reliable concepts or ideas about the world (i.e. hypothesis-theory formulation), and (2) the encounter with novelties (anomalous data) in scientific investigations. Scientists may view either or both of these factors as necessary for discovery, depending on the particulars of a specific situation. Whereas the second factor often, but not always (e.g. Brewer and Chinn 1994), provides an impetus for the first (e.g. Darden 1992), the first factor can occur independently of the second (e.g. Chi 1992; Gooding 1992). Exactly where discovery stops and justification begins is viewed as a moot issue in contemporary philosophy of science. Instead, discovery is now seen as a continuum that includes both the invention of new ideas and the validation of these ideas. Thus, discovery and justification are intertwined, rather than discrete components of scientific inquiry.

Recent work has not focused on the development of a formal logic of discovery, such as the logical analysis empiricists developed for justification, but on efforts to determine the heuristics, or general rule-based strategies, that underlie aspects of scientific inquiry that lead to discoveries (Kleiner 1993). The most formal analyses of this type have been conducted by those interested in artificial intelligence, some of whom have developed computational algorithms of discovery (Simon 1973, 1977; Langley et al. 1987; Kulkarni and Simon 1988; Thagard 1988; Shrager and Langley 1990).

Other work on heuristics has been of a less formalized nature, attempting only to identify components of scientific inquiry that appear to play a role in discovery in at least some instances. A general theme that has emerged from this type of analysis is that most discoveries occur within a context of background information, including those based on serendipity (e.g. Kantorovich and Ne'eman 1989; Kleiner 1993, p. 308), analogical and imagistic reasoning (e.g. Nersessian 1992), or abductive inference (e.g. Kapitan 1992), all of which have been discussed by geomorphologists interested in the discovery process

(Gilbert 1886, 1896; Baker and Twidale 1991; Rhoads and Thorn 1993). Background information includes deeply ingrained metaphysical beliefs about the nature of reality (e.g. Dilworth 1994), presuppositions that influence decisions about the 'best' way to explain this reality (e.g. Barnes 1995), and accepted scientific knowledge (Kleiner 1993, pp. 59-86). This information guides discovery by constraining the range of possibilities when formulating or entertaining new theories or hypotheses. In the earth sciences, principles from physics, chemistry, and biology, as well as accepted knowledge within a specific discipline, often provide relevant background information for constraining the range of possible explanations of new situations (Kitts 1982; Bardsley 1991; Rhoads and Thorn, Chapter 2 this volume). The extent to which a particular item of background information constrains possible new hypotheses is usually in direct proportion to the extent to which that item is held to be true. Through detailed examination of investigations that have led to discoveries in geomorphology, the discipline may develop a better understanding of the reasoning processes that underlie geomorphologic inquiry and the relationship of these processes to those in other areas of science.

GENDER ISSUES

Prior to 1950 geomorphology was almost exclusively a male preserve. Over the past 45 years the number of women geomorphologists has increased dramatically. Despite this increase, women are still a distinct minority in the discipline; geomorphology remains a male-dominated scientific field. In this sense, the gender structure of geomorphology is similar to that in other physical-science and engineering-related disciplines (Sonnert 1995).

The increasing presence of women in science at large has raised some practical issues related to gender, such as concern about equality of access for women with regard to educational opportunities (Matyas and Dix 1992; Ginorio 1995) and science-related careers (Vetter 1992; Rayman and Brett 1993; National Research Council 1994), of which geomorphologists should be made aware. The effort to include female authors in this volume serves as an example of the practical challenges facing women scientists today. Two women who agreed to contribute chapters had to cancel their commitments immediately prior to the deadline for submission because of unanticipated personal situations which required their immediate and full attention. These situations were not, by necessity, uniquely female, but they were ones in which women often are expected to assume a disproportionate share of responsibility relative to men. Although social expectations based on gender are less prevalent today than in the past, they still exist to some extent. Men in a male-dominated discipline must not only contribute to the dismantling of such stereotypes, they must also be sensitive to the ways in which the persistence of such stereotypes can obligate women differently from men.

The increasing infusion of women into science has also had an influence on the philosophy of science through the development of gendered and feminist perspectives on contemporary science (Keller 1985, 1992; Bleier 1986; Harding 1986, 1991; Haraway 1989; Tuana 1989; Code 1991; Alcoff and Potter 1993; Shepard 1993; Rose 1994; Spanier 1995) and on the history of science (Benjamin 1991; Scheibinger 1993). Much gender-oriented philosophical analysis is highly naturalized and postmodern, drawing upon work in behavioral psychology, Marxist theory, and sociology of science for its inspiration. Most of this work is directed at offering constructive critiques of contemporary science, focusing in particular on the influence of masculine ideology on the scientific enterprise, with the hope of illuminating how such ideology can obstruct scientific objectivity. Feminist epistemology takes the critique to the next level by arguing that women, as marginalized persons in science, are in a privileged epistemic position to recognize, expose, and correct male-related bias in scientific inquiry, thereby enhancing the objectivity of this inquiry (Hartsock 1983; Rose 1986; Haraway 1988; Harding 1993). Although this claim is controversial (e.g. Pinnick 1994), it appears to be relevant in at least some scientific contexts, particularly in studies in which the subject matter is directly or indirectly related to women or gender (Sismondo 1995). Other feminist philosophy of science has employed psychoanalytic theory on personality development in an attempt to understand the nature of science as a human endeavor (e.g. Keller 1987). According to this perspective, science can be seen as a dialectic between the desires for mastery over, and union with, nature. On the one extreme, knowledge obtained through detached, objective scientific analysis that emphasizes the use of quantitative models and empirical data can be pursued to gain some measure of power or control over the world. This image of science reflects aggressive, autonomous human behavior. At the other extreme, scientific research may employ qualitative methodologies in an effort to converse with nature or to let the data suggest the answer to a problem. The goal here is simply the pleasure associated with knowing the world so that we might better appreciate it and our place within it - an image that reflects romantic predilections. According to Keller (1987) examples of these dialectic elements can be found throughout science, both now and throughout the history of science. The contrast between certain chapters in this volume suggests that this dialectic also exists in geomorphology. Although the components of the dialectic may be somewhat exaggerated, stereotypes about scientific style, whether perceived or real, can have an important influence on how attractive a particular discipline is to individuals with particular types of personality traits. Such stereotypes are shaped not only through exposure to actual research in the discipline, but also through educational experiences.

The emergence of gender-related issues in science has not escaped the attention of some women geomorphologists, especially those affiliated with the discipline of geography, where interest in feminist approaches to human geography has exploded over the past several years (e.g. Hanson 1992; McDowell 1992; Rose 1993; Monk 1994). An open forum on physical geography entitled 'Is Gender an Issue?' was conducted by the Women in Geography Study Group (WGSG) in September 1995 at the Royal Geographical Society, London, UK. The goal of the forum was to initiate discussion and exchange ideas about women, gender, and physical geography (Joanna Bullard, 1995, personal communication). Several questions served as an impetus for discussion (Table 5.3). Although no serious problems related to gender were identified at the forum, several concerns were raised (Table 5.3). This initial meeting did not consider in depth the possible role of feminist theory in physical geography, but the nature of the concerns identified at the meeting suggests that further exploration of the relevance of feminist epistemology and methodology to geomorphology may be worthwhile. For example, the concern about possible overemphasis on quantitative methods and empirical analysis in physical geography (Table 5.3) is consistent with many feminist epistemologies. A possible point of

Table 5.3. Focus questions for the open forum on physical geography and gender-related concerns emerging from the forum

Focus questions:

Can we attract more women to undergraduate courses in physical geography'?
Why do so few female physical geographer postgraduates go on to become lecturers?
Is there a role for a feminist physical geography?
What is the role of the WGSG in physical geography?

Concerns raised at the forum:

Female role models are important for attracting female undergraduates, but the most important attributes of the teacher/lecturer are enthusiasm for the subject and the ability to make course material interesting.

On undergraduate field trips the presence of a female staff member is important in moderating the often male-dominated environment, but so too is a balance between male and female students.

At graduate or postgraduate level there is sometimes the expectation that women participants on a field trip will cook and clean up.

Physical geography is seen as a discipline in which quantitative data and statistical analysis are valued and the more philosophical side of the discipline is undervalued. One must first prove one's ability as a 'hard' scientist before engaging broad philosophical issues.

Questions asked of applicants for undergraduate degree programs and academic jobs are often inappropriate in the sense that they are gender-specific. An example is concern about the physical capabilities of women in performing fieldwork.

Teaching of physical geography at the undergraduate level often emphasizes a 'continual onslaught of equations' in the context of an insipid style of presentation. This approach to teaching is inaccessible and unappealing.

departure for future debate about this issue is the controversy over the role that quantification should play in feminist-oriented research in human geography (Mattingly and Falconer-Al-Hindi 1995; McLafferty 1995; Moss 1995; Lawson 1995; Rocheleau 1995).

APPLIED STUDIES

One of the most fundamental changes that has occurred in geomorphology over the past several decades is the dramatic increase in the number of studies with an applied dimension. The original purpose of geomorphology, to provide knowledge of the evolutionary history of landscapes, has been supplemented by the goal of explaining and predicting landscape dynamics for societal benefit. This supplemental focus implies that geomorphological studies conducted on human time scales no longer need to be justified solely on the basis of their contribution to the goal of understanding geologic-scale landscape evolution. It also raises some interesting philosophical and ethical issues.

The distinction between basic and applied science is common, but ambiguous. Although most scientists distinguish between basic and applied research, this distinction rests mainly on an intuitive foundation. The tension involved in drawing the distinction is reflected in the well-known cliche that all scientific knowledge has practical value, albeit perhaps in a highly indirect and unforeseeable manner. Nevertheless, because the distinction between basic and applied research often enters into political policy decisions that directly affect science (i.e. government decisions about science policy and funding) (Graf, Chapter 18 this volume), consideration of this issue is important, if not for intellectual reasons, then for pragmatic purposes.

Traditional philosophy of science has been largely unhelpful in illuminating the philosophical basis for the basic versus applied distinction because it has focused mainly on what both philosophers and scientists would characterize as basic research (in the intuitive sense). Recently, however, some philosophers of science have begun to direct attention toward this issue, especially with regard to the distinction between science and technology (e.g. Bunge 1985; Kroes 1989; Ihde 1991). While recognizing that scientific research forms a broad continuum that does not allow for dichotomous categorization, this work does maintain that distinctions can be made between characteristics of research in disparate portions of the continuum. Much of this work has challenged the standard conception that science and technology are connected in a directed, linear manner with technological knowledge consisting in nothing more than applications of scientific knowledge within specific contexts.

One useful way to characterize the distinction among basic science, applied science, and technology is on the basis of differences in the utilities that define the aims of inquiry and in the structure of scientific statements (Niiniluoto 1993). The primary aim of basic research is generally viewed as the purist ideal of science: to accurately explain and understand reality. Thus, the epistemic utilities of truth, knowledge, and explanatory power serve as cognitive virtues at this level. At the other extreme, the aim of technology is to produce artifacts that create new possibilities of action for humans in their interaction with the world. The utility underlying this aim is a practical one: the effectiveness of the artifact relative to its intended application. In between, the aim of applied science is not to produce artifacts, but to produce information that can be used either for prognostication or for enhancing the effectiveness of human actions. The utilities of applied science often are a mix of the epistemic utilities of basic science and the practical utility defined by the value of the information in relation to human concerns or goals.

Differences in the structure of scientific statements can also be identified among various types of scientific research (Table 5.4). Descriptive statements are stated in language that is meant to be value-neutral (factual statement in indicative mood), although this trait does not guarantee that the statement is completely value-free in the sense that the selection of the scientific problem underlying the claim and the process of establishing the content of the claim do not involve value judgments on the part of scientists. When explanation is the aim, statements that specify cause usually are preferred, whereas when the aim is predictive power, statements that identify a reliable (but not necessarily causal) relation between two variables are desired. Technical norms, on the other hand, combine a categorical normative statement (you ought to do X) with a statement about want or preference. Although technical norms include an explicit statement about valuation, usually of an ethical nature (i.e. you want or desire A), such statements are still capable of being analyzed scientifically once this valuation is fixed by some process external to science (e.g. Hempel 1960). In other words, scientific testing can still reveal whether doing X achieves A.

The criteria of utility and type of scientific statement can be combined to identify four different types of scientific research along a continuum ranging from descriptive basic science to technology (Table 5.4). Specific examples from fluvial geomorphology illustrate how this characterization of science and technology applies to geomorphology. Most work in geomorphology to date generally falls within the categories of basic, descriptive science or applied, predictive science. The increasing visibility of geomorphologists in

Table 5.4. A scheme for characterizing basic science, applied science, and technology in geomorphology (adapted from Niiniluoto 1993)

	Primary utilities defining aim of scientific research	Structure of scientific statements	Example from fluvial geomorphology
Basic, descriptive science	Epistemic: truth, knowledge, explanatory power	Descriptive, causal [X causes A in situation B, or X tends to cause (with probability p) A in situation B]	Research on meandering e.g. Dietrich and Smith (1983)
Applied, predictive science	Mix of epistemic and practical with emphasis on predictive power of scientific information	Descriptive, relational [X is related to A (with probability p) in situation B]	Threshold functions of human-induced channel instability e.g. Brookes (1987)
Applied, design science	Mix of epistemic and practical with emphasis on usefulness of information for developing technological artifacts	Technical norm [if you want A, and believe you are in situation B, then you ought to do X]	Development of river restoration/management guidelines based on geomorphologic principles e.g. Brookes (1995)
Technology Professional problem solving	Practical: effectiveness of technological artifacts for achieving human goals	NA	Implementation of restoration schemes based on geomorphological principles e.g. Brookes (1990), Rhoads and Herricks (1996)

professional roles has also initiated the development of applied design science components in some areas of the discipline. This type of science, which draws upon principles derived from descriptive basic and applied sciences, directly supports the development of problem-solving tools and skills needed to support a professional practice. However, the relationship among these components is not a unidirectional, linear path from basic science to technology. In some cases, existing scientific knowledge or information to support a particular technology may be poorly developed (Figure 5.2) and the constraints of time or money may not allow for testing of normative statements to determine their validity. In such cases, a 'trial and error' approach may be adopted at the technological level, which in turn may lead to the formulation of technical norms. Moreover, because these norms include statements about relations between variables found in descriptive scientific statements, information generated by 'trial and error' at the technological level occasionally may be relevant to the evaluation of knowledge claims in basic, descriptive science.

This depiction of the relation between basic science, applied science, and technology suggests that the growth of geomorphology as a practical profession requires that geomorphologists continue to devote effort to developing and refining a design science to

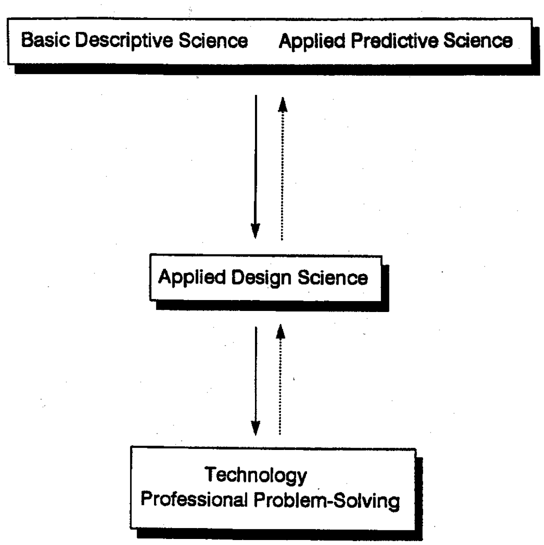

Figure 5.2. Relationships among basic science, applied science, and technology. Knowledge and information from basic descriptive science and applied predictive science provide support for an applied design science, which in turn sustains some technology or profession (practical problem-solving). On the other hand, trial and error efforts (usually in situations for which the design science provides little guidance) at the professional or technological level can lead to improvements in the design science, which in turn can contribute to knowledge in basic descriptive science. For exarnple, trial and error attempts at stream-channel restoration could generate information that proves useful for improving restoration guidelines (technical norms) (e.g. Table 5.4). Moreover, this information may have value for basic descriptive science and applied predictive science if it leads to improved understanding of the basic mechanisms governing river-channel dynamics, thereby allowing for more accurate predictions of river response to human disturbance

support this profession. Such a design science can provide the basis for professionalization of the discipline by codifying a body of information, tools, and skills for licensing or certification programs. Establishment of a design science, however, represents only one aspect of the effort to professionalize geomorphology. Because geomorphologists involved in applied design science and professional geomorphologists both deal with technical norms, which are explicitly value-laden, the issues of moral responsibility and professional ethics become a concern. As noted by Niiniluoto (1993), a person who implements technical norms or who helps to establish ways of attaining these norms is morally responsible for helping to effect the valuations stated in these norms. Little or no attention has been given to ethical issues in geomorphology. Although most applied work in the discipline appears to rest on an underlying environmental ethic, the exact nature of this ethic and its potential implications for a professional code of conduct have yet to be explored in detail (Pierce and VanDeVeer 1995).

CONCLUSION

This chapter has introduced a variety of philosophical topics, the exploration of which may shed light on the scientific nature of geomorphology and the ways in which geomorphology is similar to and different from other scientific disciplines. The choice of topics has been selective, and a host of other issues in the philosophy of geomorphology may also be worthy of investigation. Some geomorphologists may remain unconvinced that philosophical analysis has anything useful to offer to the discipline. For them, it is time to head to the field. On the other hand, the chapters in this volume show that some geomorphologists are interested in, and maybe even concerned about, exploring more fully the scientific nature of geomorphology. Certainly, this chapter should not be viewed as a call for a vast number of geomorphologists to become philosophers. As scientists, geomorphologists should primarily practice science, not philosophy. On the other hand, given the extent to which philosophical discussion of geomorphology has been avoided in the past, a small to moderate dose of philosophy will probably not hurt us too much, and, who knows, it may contribute something of genuine value, not only to geomorphology, but to philosophy of science as well. Now where is that soil auger?

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