Chapter 1
The Globalization of Knowledge in History: An Introduction

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1.1 The Development of Knowledge as a Global Learning Process

Much of today's knowledge, whether scientific, technological or cultural, is shared globally. The extent to which globalized knowledge existed in the past remains an open question and, moreover, a question that is important for understanding present processes of globalization. Considering, for instance, the rapid spread of the wheel throughout Eurasia in prehistory, the spread of Roman law to such diverse areas as the Byzantine Empire and Ethiopia, and the global spread of paradigmatic solutions in architecture such as the Gothic arch, one is led to conclude that a lively exchange existed between cultures in all periods of human development.

In recent years, investigations of the migration of knowledge and comparative historical studies have become active fields of research. With few exceptions, however, the emphasis is placed mostly on local histories focusing on detailed studies of political and cultural contexts and emphasizing the social construction of science. While this emphasis has been extremely useful in overcoming the traditional grand narratives and in highlighting the complexity of these processes and their dependence on specific cultural, social or epistemic contexts, it has also led to an underestimation of the extent to which the world has been connected, for a very long time, by knowledge. The results deliver a rather fragmented picture that tends to neglect the fact that knowledge transmission concerning, for instance, agriculture, architecture, language, writing or calculating, may have been part of long-term and indeed global processes since very early times and can only be properly understood from a more comprehensive perspective.[1]

The central thesis of this book is that, just as there is only one history of life on this planet, there is also only one history of knowledge. Of course, there have been major losses of knowledge and innumerable new beginnings, and there may be as many perspectives on knowledge as there are cultures, if not people who have lived on this planet. But variety, contingency and catastrophic interruptions are also familiar from the history of life. What counts is that both in the history

[1] This has been observed recently also by Sujit Sivasundaram (2010). For recent, more broadly conceived approaches, see (Lloyd 2002; Huff 2003; Ash 2006; Harris 2006; McClellan and Dorn 2006; Costanza et al. 2007; Cohen 2010; Huff 2011; Schäfer 2012). For a general overview of knowledge in non-Western cultures, see also (Selin 1997; Günergun and Raina 2011).

of life and of knowledge, there is a stream of historical continuity with cumulative effects on a global scale, effects that are elusive to predominantly local studies and that account for a highly fragmented, but nevertheless inexorable global learning process, where "learning" is not understood as necessarily indicating progress, but rather as referring to the developmental and evolutionary character of this process, which will be discussed in the following.

1.2 The Role of Knowledge in Globalization Processes

1.2.1 Beyond Economic Globalization

Science in the twenty-first century represents globalized knowledge and benefits from the creation and exploitation of new social and technological structures which enable the global free flow of knowledge and expertise. It could also benefit, however, from a historical awareness of the ways in which techniques and technology in the past have spread throughout the world. The present lack of this awareness hinges on a structural deficit of research in this field due to disciplinary boundaries and fundamental epistemic limitations. This book aims at taking a first step toward overcoming this deficit.

The much-discussed globalization process of the present refers mainly to the economic processes of globalization of markets for goods, capital and labor,[2] whereas the global diffusion of technical innovations and bodies of knowledge is often considered as a mere presupposition or consequence of economic, political and cultural processes.[3] But globalization involves knowledge in more significant ways. Moreover, the globalization of knowledge in the sense of a global interconnectedness of human knowledge is not only a phenomenon of the present age. Our situation today may rather be understood as the result of historical processes that already comprise many dimensions characterizing modern globalization processes, each with its own peculiar constellation of economic, political, technical and cultural means of social cohesion.

Investigating the role of knowledge in these historical processes and referring such an analysis to the present may present opportunities for regaining autonomy with regard to the economic dimension dominating our current perception of globalization processes. An investigation of this kind may indeed explain the sense in which the globalization of knowledge has become a critical dimension of today's globalization processes on which their future development depends. From this perspective, they may turn either in the direction of subjecting the economy of knowledge to the control of other globalization processes, or in the direction of strengthening the autonomy of knowledge and thus its potential for steering such processes.

[2] See, for example, (Ziegler 2008).

[3] For a survey of the current literature on globalization and the role of knowledge and science in it, see chapter 2.

Recent discussions about globalization processes emphasize two apparently contradictory characteristics of such processes: homogenization and universalization, on one hand, and their contribution to an ever more complex and uncontrollable world, on the other.[4] Indeed, the economic power of globally organized transnational corporations increasingly translates into a standardization of mass culture and universal tendencies of wasteful consumption of natural resources. Contrastingly, due to the unequal distribution of wealth, among other factors, the same pressures of homogenization provoke an increasingly diverse spectrum of strategies to cope with these pressures, which leads to an increasingly complex patchwork of social relations. National and regional institutions and traditions in fact play an often neglected mediatory role in filtering and transforming the effects of globalization.

Such observations point to the possibility that the alternative between an increasingly homogenized "flat world" and an increasingly complex network of social relations may be insufficient to capture the dynamics of globalization processes.[5] Evidently, globalization comprises the transcultural diffusion, integration and transformation of a broad variety of means of social cohesion, ranging from goods to language, to belief systems and political institutions. Globalization thus results from a variety of processes, all characterized by the tension between unification and growing complexity.

Economic globalization, for instance, extends the dominance of the world market over local patterns of production and distribution (Wallerstein 1976; Pomeranz and Topik 1999) and, at the same time, provokes counterstrategies for developing diverse local patterns of economic subsistence under the new preconditions (Sahlins 2000). Globalization homogenizes culture and destroys local customs, but it also stimulates morally grounded anti-globalist countercultures, as well as fundamentalism (Robertson 1992). In the field of political decision structures, globalization leads to a growing number of international institutions whose task it is to deal with problems transcending the influence spheres of political institutions of national states (Kratochwill and Mansfield 2006). While globalization thus questions national autonomy from the perspective of global requirements, national integrity is, at the same time, also menaced by a growing tendency toward new regional units (Bowles and Veltmeyer 2007).

1.2.2 Globalization as a Superposition of Various Layers

The contrast between the tendency toward an ever "flatter" and an increasingly "fractal" world (Deleuze and Guattari 2011) suggests that comprehensive globalization processes result from a superposition of various layers, such as the migration of populations, the spread of technologies, the dissemination of religious ideas or

[4] See (Nancy 2002; Sloterdijk 2005; Friedman 2005, 2008).

[5] See (McNeill and McNeill 2003; Friedman 2005; Buchholz et al. 2006; Hofäcker et al. 2006; Mönch 2008).

the emergence of multilingualism. While these processes each have their own dynamics and history, it is their interactions and in particular their involvement of knowledge which marks globalization as we observe it in the present. Considering, for instance, the creation of social identities, it is clear that bodies of knowledge in transition are always carried by agents whose identities are constructed in relation to the knowledge they bear from their place of origin, but also in relation to new kinds of knowledge they encounter in the new space. In the globalization processes of the recent past, with migrations that have rapidly diffused knowledge and behavior (Hoerder 2002), traveling knowledge has had the effect of constantly deconstructing familiar boundaries and producing new identities and solidarities. This pattern of globalization processes is familiar, at least since the age of colonization, and is constitutive of the national and cultural identity of post-colonial societies.[6]

Goods, tools, inventions, suggestions, technical skills and ingenious solutions circulate among human groups with different rates of diffusion, but typically faster than languages, values, traditional rituals, systems of ideas or religious frameworks, and, in particular, administrative and political institutions. These differences in rate account for the characteristic retardation of globalization processes after the realization of their initial incentives. They are, at the same time, indicative of the crucial role of knowledge in these processes.

It is of central importance to observe that goods and the technologies that produce them often spread independently of each other and are each associated with systems of knowledge that make them relevant and accessible to a given culture. The transfer of the knowledge necessary for producing and inventing tools requires, in particular, linguistic capabilities and frameworks of ideas which can only be built up once globalization processes of other types have taken place. Against this background, the crucial role and long history of multilingualism, for instance, going back to ancient scribal cultures, becomes understandable as a critical factor in globalization processes. The relation of the different layers partaking in comprehensive globalization processes is not just one of mechanical succession, otherwise one could be certain that the globalization of markets, for example, implies a globalization of the political system, which is clearly not the case. Rather, the interaction between the various layers may lead to very different outcomes of globalization.

It is generally accepted that knowledge partakes in globalization processes.[7] It even constitutes a specific condition for every form of their realization. On the political level, the spread and improvement of education is considered to be critical for mastering the challenges of globalization, which are constituted as well by the tensions between its different layers. One example is the challenge of mutually adjusting new technologies, on one hand, and traditional behavioral patterns such

[6] See (Feldhay 2004; Lerner and Feldhay forthcoming).

[7] See (Manning 2003; Bayly 2004; Gruzinski 2004; Osterhammel 2009). See also the survey chapter 9.

as learning to handle instruments and machinery by trial and error, on the other. This challenge can hardly be addressed by focusing only on traditional school education.

Globalization processes such as the exchange of technology or migrations of people thus obviously presuppose the diffusion of knowledge: the knowledge of how to deal with the technical means transferred and the knowledge of how to establish life under new circumstances, respectively. Similarly, knowledge is clearly a consequence of globalization processes, just as the exchange of goods or the diffusion of a language also transport knowledge. Knowledge, however, does not just constitute one more aspect of globalization as a precondition and consequence, but represents a critical element of its development. It is in fact the globalization of knowledge as a historical process with its own dynamics that orchestrates the interaction of all the underlying layers of globalization. The globalization of knowledge not only constitutes a relatively autonomous process in its own right, but profoundly influences all other globalization processes—including the formation of markets—by shaping the identity of its actors as well as of its critics.

Accordingly, education is a precondition of globalization processes as well as a consequence of their realization, but the transmission of knowledge through education is only one—and not necessarily the decisive—type of social interaction to determine the development and diffusion of knowledge in globalization processes. It is a central claim of this book that the function of knowledge in such processes cannot be reduced to a precondition or a consequence, neither of which accounts for the emergence of innovations in globalization processes. Rather, the function of knowledge in globalization processes embraces the co-development of knowledge, technology and social interaction. This co-development gives rise to unexpected novelties, such as the origin and spread of writing, the development of printing technology and of the Web, the emergence of social mechanisms for distinguishing knowledge from belief, and the creation of social identities that are structured around the possession of a certain type of knowledge.

1.2.3 Prolegomena to a Global History of Knowledge

In this book, we propose to study the globalization of knowledge in history in this comprehensive sense, from the spread of technological knowledge in prehistoric times to the consequences of the Web for a new economy of knowledge. In the past, challenges such as an unstable equilibrium of population density, the scarcity of nutrition resources, a change in ecological conditions, the emergence of new knowledge or new technologies, or shifts in economic and political power structures triggered phases of intense globalization. One important task of a history of the globalization of knowledge is to identify bodies of shared knowledge that, in these phases of intense globalization, were crucial for the corresponding diffusion and transformation processes. In the following chapters, we deal with the emergence and spread of agricultural knowledge, early key technologies such as ceramics and metallurgy, and with the emergence and spread of writing. But, we are

also concerned with the reflective knowledge embodied in religious, philosophical, artistic and scientific traditions, and with modern globalized science, in particular, with models for global knowledge interactions including the mass media and the Internet.

Although a wide range of topics is covered, there is no pretense at a comprehensive history of the globalization of knowledge. Our aim is rather to show, by using examples, how the diffusion of knowledge throughout history can, in principle, be explained in terms of a historical epistemology, paying close attention to the structures of knowledge involved.

A systematic account of the globalization of knowledge in fact has not arisen for two reasons: first, the manifest diversity of data needed, and second, the less obvious lack of a common theoretical language for describing types, media and transmission processes of knowledge. To overcome the first of these problems, we have assembled a number of contributions from various fields, ranging from archaeology and ancient history, via the history of religion and science, cultural anthropology, to the modern natural sciences. Based on these examples, we propose a theoretical framework that is outlined in the following section. Widening the range of examples in future studies will certainly revise some of the general conclusions about the globalization of knowledge that we have tentatively reached in this volume. Our main goal here is to illustrate how such case studies might help in developing a new theoretical language.

1.3 A Theoretical Framework for Studying the Globalization of Knowledge

1.3.1 What Is Knowledge?

A common theoretical language for addressing the issue of globalization of knowledge from a comparative perspective must be both expressively rich and structurally simple. It must draw on established insights from cognitive science, philosophical epistemology, anthropology, archaeology, historical disciplines including the history of science, the history of art and the social sciences; it must moreover encompass the full range of developmental processes implicated in the global spread of knowledge throughout history. No existing academic discipline provides all the tools required.

Knowledge is conceived here as the capacity of an individual, a group, or a society to solve problems and to mentally anticipate the necessary actions. Knowledge is, in short, a problem-solving potential. Knowledge is often conceived (especially in disciplines such as psychology, philosophy and the cognitive sciences) as something mainly mental and private. But from the historical and social viewpoint, it is necessary to consider knowledge as something that moves from one person to another: something that may be shared by members of a profession, a social class, a geographic region or even an entire civilization. From this perspective, knowledge and its movements may be mapped. Shared knowledge is

especially important to the artistic, religious, legal and economic systems that constitute cultures; and knowledge travels along with artifacts and artistic styles, myths and rituals, laws and norms, goods and wealth.

Not only is knowledge situated in time and space, but so too is thinking. Recently, the latter phenomenon has come to be studied in cognitive psychology under the term "distributed cognition" (Perry 2003). The work of cognition is not confined to the individual mind but can be distributed among groups of people. What makes this distribution possible are external representations of knowledge such as spoken language, writing and technological artifacts. Through such external representations, knowledge is transported from one mind to another and thinking takes on a social dimension. For example, one may consider how the planning of complex tasks for the construction of the New Kingdom tombs in the Valley of the Kings was distributed among the various workers and craftsmen living in the Egyptian city of Deir-el-Medina, each of whom possessed different skills, knowledge, cognitive abilities and cognitive styles. Or one may consider how Euclid in *Elements* integrated the results of many earlier mathematicians into a complex and novel system: Euclid's *Elements* thus represent the productive thinking of not just one single man, but of many.

It is typically from external representations that the shared knowledge of a society is, in part, appropriated by an individual (Damerow 1996). The tension between shared and individual knowledge is a fundamental one. It also involves the creative tension between explicit and tacit knowledge that Michael Polanyi discusses (Polanyi 1983). It is only through individuals that new knowledge can be produced, and it is only through societies that it can be reproduced. The differing aspects of the shared knowledge that is appropriated by individuals or groups in a society are closely linked to their identity and self-awareness. I know who I am because I am what I know.

Knowledge has a systemic quality: elements of knowledge are typically part of a network with differing degrees and types of internal organization. This is relevant to knowledge transmission processes because they often involve only the partial transmission of such a network. In some cases, the network may have been transmitted only in fragments, but it may nevertheless still be possible to reconstruct the entire system from them; the reconstruction may, however, also fail or lead to an entirely new system. One example is the earliest attempts at reconstructing ancient scientific theories in the Renaissance from just a few fragments of the classical texts.

Here, knowledge is seen as evolving from individual and collective processes of reflection. Knowledge about things is inseparable from knowledge about knowledge with regards to, for instance, its range, its certainty, its origins or its legitimacy. Knowledge is thus never simply "first-order" knowledge about some concrete or abstract object but always involves knowledge about this knowledge as well, that is, meta or second-order knowledge. This reflexivity of knowledge also accounts for its self-organizing, self-promoting qualities. Second-order knowledge is the origin

of curiosity because it involves an awareness of the ever-present limitations of the available knowledge.

The reflection of knowledge presupposes its external representation. Reflection on knowledge is typically a reflection on the external representation of knowledge, as when Euclidean geometry emerged from the reflection on the practice with ruler and compass. As a result, knowledge has a complex layered structure closely tied to concrete forms of representation, ranging from written or iconic representations to social structures or rituals. Also, the articulation and spread of more reflective knowledge follows different patterns than the use and mobility of less reflective knowledge. Thus, knowledge about the existence of artifacts, such as balances, travels much more easily than the knowledge required for their manufacture represented by tools and procedures, let alone the knowledge associated with an abstract concept of weight, represented by written texts.

In the following, we introduce a core set of concepts which are extended and elaborated upon in the survey chapters that introduce each of the four parts of the book. The basic concepts required include a typology of "knowledge forms," "knowledge representation structures" and "knowledge transmission processes." Other concepts we make use of include vehicles for the transmission of knowledge, epistemic networks, knowledge economy, knowledge systems, packages of knowledge, layers of knowledge, epistemic and socioepistemic evolution. Here, we limit ourselves to a discussion of only the most basic concepts.

1.3.2 Forms of Knowledge

Forms of knowledge vary along three basic dimensions: distributivity, systematicity and reflexivity. In terms of distributivity, they range from universal knowledge, acquired in ontogenesis by every human being, to knowledge that is specific to individuals, or shared in social groups, social strata or geographic regions. Knowledge can also be systematized to varying degrees, ranging from isolated chunks of knowledge, via packages of knowledge to more or less coherent systems of knowledge. Forms of knowledge are furthermore distinguished by their degree of reflexivity, which is indexed by the distance from concrete objects manipulated in the course of elementary existence. Reflexivity in this sense is lowest in the case of "intuitive knowledge," that is, unaccompanied by conscious reflection and unmediated by symbolic forms; it is highest in the case of "second-" or "higher-order knowledge," also called "meta-knowledge," where the object of knowledge is itself a form of knowledge.

The range of knowledge forms with different degrees of reflexivity includes the following, strongly overlapping categories:

1. intuitive knowledge
2. practitioners' knowledge
3. symbolically represented knowledge

4. technological knowledge (determined by ends)
5. scientific knowledge (determined by means)
6. second- and higher-order knowledge.

Higher-order knowledge includes any form of knowledge generated by processes of reflection, such as abstract arithmetical knowledge resulting from a reflection on the practice of counting. This classification elaborates on the distinction between bodies and images of knowledge introduced by Yehuda Elkana.[8] In the sequel, second-order knowledge mostly refers specifically to images of knowledge in the sense of that part of the shared knowledge of a society or group that governs its ways of handling and valuing knowledge. This second-order knowledge is also designated as the second-order or epistemic framework of a group or society. Knowledge and second-order knowledge cannot be separated in any absolute way, however, as they always occur simultaneously. Knowledge is invariably part of a system in which it receives its meaning by being related to other knowledge, while this other knowledge, in turn, receives its meaning reciprocally from the given knowledge. As a consequence, knowledge always serves, at the same time, as knowledge about the world and knowledge about other knowledge.

1.3.3 Representations of Knowledge and Knowledge Economy

The mechanisms for the production, dissemination and appropriation of knowledge in a society or group constitute its knowledge economy,[9] dependent on its material culture, on political, economic and cultural boundary conditions, but particularly on its second-order epistemic framework as well. Considered from this perspective, the knowledge economy of a society or group is also designated as its dominant epistemic constellation. Thus, in a theocratic society, its epistemic framework might be constituted by views on knowledge gathered in certain holy writings, while its dominant epistemic constellation includes all the rituals by which this knowledge is disseminated and appropriated.

Knowledge representation structures have been extensively studied in the framework of cognitive science and artificial intelligence focusing on the question of how people store and process information in their minds. An analysis of historical processes of knowledge development and diffusion, however, makes it necessary to extend this notion in two dimensions to cover not only internal but also external representations, and not only individual but also shared knowledge. External representations are the currency of a knowledge economy. They involve the use of knowledge representation technologies ranging in complexity from notches carved on a stick as a simple tallying mechanism to sophisticated

[8] For the concept of images of knowledge, see (Elkana 1981). See also the work of Yaron Ezrahi (1995) on civic epistemology.
[9] See also (Dunning 2000).

computer systems.[10] Understanding how knowledge is stored, processed, disseminated through space and transmitted through history requires taking into account that individual knowledge generally results from the individual appropriation of shared knowledge by reconstructing it from external representations.

For this reason, knowledge representation structures relevant to the processing of shared knowledge are primarily characterized by the interaction of the means of external representation available in a given historical situation with individual cognitive structures such as mental models.[11] The interactional approach requires taking into account the human cognitive capabilities studied by developmental psychology and cognitive science, ranging from intuitive inferences to the reflective construction of semantic networks. It also requires addressing cultural potentials investigated by behavioral, social and historical sciences, such as comparative psychology and linguistics, sociology, economics, ethnology, archaeology and history, in particular, the history of technology, science, religion and art.

1.3.4 Mental Models in the Transmission and Transformation of Knowledge

The history of knowledge has been studied mostly from a restricted perspective that favors innovation over transmission and transformation.[12] Historians of science and technology have often focused on the question of who was the first to discover a fact that later became a key innovation and when this took place. Much less attention has been paid to the question of what role these discoveries or inventions played in the contemporary context of knowledge and how they changed their meaning when transmitted to a different context. What kind of less spectacular knowledge enabled the celebrated discoveries and inventions in the history of science and technology? How was a discovery or invention interpreted by contemporaries? How did the discovery or invention influence the further development of science and technology? What is the relation between the empirical discovery of a fact and its derivation in a theoretical framework? What is the relation between a technical invention and its implementation as a societal innovation? How do transmission processes change the perspective on a technological or cognitive achievement?

To respond to historical-epistemological questions of this kind, an understanding is required of how reasoning operates in frameworks of knowledge that are not mathematized or otherwise structured as a deductive system and that differ even in their conceptual structure from later science. This becomes particularly relevant for understanding globalization processes of knowledge. To account for an important aspect of such types of reasoning, we make use of concepts of cognitive science, in particular of the concept of "mental model." Mental models are specific

[10] This is explored in more detail in chapter 3, section 3.12 and chapter 32, section 32.5.
[11] See (Gentner and Stevens 1983; Damerow 1996; Renn and Damerow 2007).
[12] The following framework is based on joint work with Peter Damerow, see (Damerow 1996; Renn 2007; Renn and Damerow 2012).

types of internal knowledge representation structures that allow inferences to be drawn from prior experiences about complex objects and processes, even when only incomplete information on them is available.

The concept of mental models, as used here, is a particular application of default logic. Default logic is an extension of formal logic that has been developed in cognitive science to account for deductive reasoning as it actually occurs in science, technology and everyday life (Reiter 1980; Parsons 2006). Whereas formal logic requires that the premises of correct inferences already contain complete information about the subject of the reasoning, default logic is based on the principle that inferences from prior experience may always enter the reasoning as "defaults," that is, they are taken to be true as long as there is no evidence available to the contrary. Mental models relate aggregates of knowledge that can be of quite different types, such as data, procedures or other mental models, and of diverse origin, for example, from empirical evidence, from reasonable expectations, from a preliminary hypothesis or implicitly determined by other reasoning processes.

A mental model has a relatively stable structure that connects variable inputs. We use the term "slots" to indicate the nodes in the structure which must be filled with inputs satisfying specific constraints. The mental model of a "machine" for instance, connects slots for a motor mechanism, a transmission mechanism and an operating mechanism.[13] The structure of a mental model may include complex information processing routines that transform the inputs according to the structural relations of the model. Applying a mental model presupposes an assimilation of specific knowledge to its structure. This happens with an "evaluation" of the model, that is, input information compatible with the constraints of the slots is mapped into them. The slot fillers or "settings" may have different origins. They may result from prior experience or prior reasoning (default settings). They may come from input information that has actually been acquired (input setting). They may have been inherited from a "higher-order" mental model when the actual model fills one of its slots (inherited setting). They may be represented by other mental models, procedures or similar knowledge representation structures that may or may not be already evaluated or executed (implicit setting). Or they may result from dedicated procedures that are deliberately executed in real time with the purpose of constructing inputs (constructed settings).

Filling the slots is the crucial process that decides the appropriateness and applicability of a mental model for a specific object or process. Once the mapping is successful, that is, if the input information satisfies the constraints of the slots, the reasoning about the object or process is to a large extent determined by the mental model. Internal knowledge representation by mental models has been proven to be indifferent with respect to the origins of the processed information, that is, the extent to which it stems from input, default, inherited, implicit or constructed settings. We are not dealing here with the question of how in *individual*

[13] See (Marx 1906, part 4, chap. 15).

cognition an appropriate mental model is identified and retrieved from memory, which is an important focus of cognitive science. From the perspective of historical epistemology, mental models are studied with a different emphasis: they are part of a historically transmitted architecture of *shared* knowledge that raises questions not usually posed in cognitive science.

It is possible that more than one mental model is appropriate for application to a specific object or process. In this case, different mental models are linked to each other by the settings of some of their slots to the same inputs.[14] Thus, mental models are challenged by the objects assimilated to them since originally independent domains of reasoning become connected through the object to which different mental models are applied. This may result in complex knowledge representations, but could also lead to insurmountable contradictions. When a mental model does not fit, the object of cognition may be assimilated to another model or the model is modified by accommodation to the new experience. Thus, when Europeans first entered the Americas, they were constantly confronted with the alternative between assimilating their new experiences to known schemes of classification or challenging the schemes themselves, beginning with the very question of whether they had landed in India, or discovered a new world. The application of a mental model to different objects and processes and the outcome of such applications may itself become the object of reasoning that produces knowledge (second-order knowledge). Knowledge about knowledge representation structures may in turn change these structures. Thus, the application of mental models may lead to changes in such models, not only by immediate accommodation in reaction to insufficient fit, but also by deliberate reorganization as a result of accumulated second-order knowledge obtained by reflection.

The concept of a "mental model" is closely related to the concept of a "model" as a corresponding external knowledge representation structure. A material model, for instance a globe as a representation of the earth, supports the use of the corresponding mental model, the idea of a spherical earth, but usually cannot substitute it. A material model is not necessarily active, it does not apply itself to an object, it does not evaluate, and as a rule, it does not even adequately indicate the difference between stable entities, such as its structure, and those that are permanently modified in the process of "running" a model, that is, its use in cognitive processes. For instance, while the material model of a house helps to visualize essential features of an architectural tradition, only its corresponding mental model can guide the actions necessary to build it. The distinction between mental and material models is crucial for a historical study of knowledge development because it provides the key concepts for understanding the culturally determined acquisition, interactive communication and the historical and geographic transmission processes of mental models. Historical epistemology is only concerned with men-

[14]For instance, a steelyard, that is a balance with unequal arms, may be regarded at the same time as a balance *and* a lever, giving rise to a new, combined mental model: the balance-lever model. See (Renn and Damerow 2012).

tal models insofar as they are socially shared models whose material counterparts partake in the knowledge economy of a given social constellation. Cognitive science does not usually deal with social processes, and its concepts and theories only insufficiently account for such processes. This is the reason why we propose the specific concept of "mental models" outlined above for the analysis of historical and geographic processes of knowledge transmission.

1.3.5 Knowledge Transmission Processes

Knowledge may travel with people or it may travel in the form of external representations. These are its vehicles. Various vehicles possess their own peculiar characteristics, such as speed of transmission, reliableness of transmission, and so on.[15]

Spoken language has always constituted one of the chief means of transmitting knowledge. Of special note here are two types of linguistic situations that were as frequent in the ancient world as in the modern: multilingualism and linguae francae. Multilingualism and language contact give rise to phenomena such as linguistic borrowing, where the import of a word from a foreign language frequently evidences the transmission of a foreign concept, and translation, where a text (oral or written) is transferred from one language to another and is inescapably altered (both in form and in content) in the process. Linguae francae constitute a strategic solution to the problem of linguistic pluralism, in which parties agree upon a single language (e.g., Sumerian, Akkadian, Aramaic, Greek, Latin) as common currency; this language can be the mother tongue of only some of the parties. Typically, linguae francae have emerged due to the exigencies of trade, but they also play a key role in knowledge (languages of learning), law (diplomatic languages) and religion (sacred languages, linguae sacrae). But in becoming a lingua franca, not only does a language change its value (in a social sense), but its terms frequently change their value (in a linguistic sense).

The invention of writing created a new and powerful tool for the transmission of knowledge since it enabled knowledge to travel, in both time and space, beyond the immediacy of the speech situation. Writing emerged in ancient Mesopotamia and Egypt, at first independently of spoken language, as a technology for the administration of centralized politico-economic systems. Over time it developed into a tool for durably representing spoken language, or more accurately, the equivalent of spoken language (language that might be spoken), its full potential being discovered only slowly and with increasing usage. With writing came metrologies, calculation techniques, and finally, the rise of the first sciences, which may thus be conceived as resulting from a reflection on the social processes of organizing labor.

Under the rubric of vehicles for the transmission of knowledge, one should not overlook the importance of artifacts that may not have been explicitly intended as representations of knowledge. A technology, or even the rumor of a technology,

[15] For a typology of transmission processes, see chapter 3, section 3.13.

may motivate the (re-)discovery of the knowledge needed to produce an artifact;[16] and careful examination of the artifact may allow one to accomplish what is today termed "reverse engineering."

Knowledge transmission processes should be studied focusing on the relation between the dynamics of invention and development on the one hand, and the preservation and transmission of established bodies of shared knowledge on the other. All of these processes are determined by diverse media of knowledge transfer, by products, tools and technologies, shared experiences, oral communication, and symbol and information processing systems. Globalization processes such as the geographical dissemination of technologies, the spread of writing, the cultural exchange between Orient and Occident, the colonization and exploitation of cultures, and the creation of global networks of traffic and communication involve specific knowledge transmission processes. Examples are the co-transmission of knowledge and technology, the institutionalized transmission of knowledge by schooling, the initiation of knowledge developments by diffusion, or the reconstruction, adaptation and accommodation of knowledge by reverse engineering. The understanding of globalization processes requires an analysis of the interaction between such transmission processes and the dynamics of invention and development to explain the various forms of globalization, such as the convergence of independent achievements, the optimization, differentiation and adaptation of technologies and ideas, the hybridization of cultural resources and the role of barriers against knowledge transfer.

1.3.6 Epistemic Networks and the Dynamics of Knowledge Development

The transmission of knowledge can be understood as taking place in an epistemic network in which the nodes (or vertices) constitute possessors or potential possessors of knowledge, such as individuals, groups of artisans or scientific communities, and the links (or edges) constitute the routes that knowledge must travel to reach from one node to another. Epistemic networks are not random networks, but rather possess a topology in which certain nodes—termed hubs—are especially important in that they are connected to many other nodes. Thus, for example, while mathematicians and philosophers were scattered throughout the Greek world, certain centers (hubs) were particularly important, such as (in chronological order) Miletus, Athens and Alexandria. The importance of such centers is not unrelated to geographic, political and economic factors. Hence the occurence of cosmological thought in Milesian thinkers such as Thales, Anaximander and Anaximenes is related to the position of Miletus at the heart of Asia Minor, a cultural crossroads to which the cosmological knowledge of the Babylonians would most likely have found its way. Similarly, the wealth accumulated by the maritime empire of Athens, together with the trade and political connections that were es-

[16] Cf. Kroeber's stimulus diffusion (Kroeber 1940).

tablished, provided the socioeconomic conditions which led to the flourishing of the arts and sciences in the Age of Pericles (Malkin 2011).

Finally, we distinguish between and "intrinsic" and "extrinsic" dynamics of knowledge development. The intrinsic dynamics of knowledge development is characterized by the interaction between knowledge forms and representation structures, triggering processes of reflection which give rise to an increasingly complex knowledge architecture. The extrinsic dynamics is determined by an interplay between epistemic, ecological, cultural, economic and political factors.

The exploration of the consequences of a given system of knowledge in a given social and cultural context and its subsequent restructuration may serve as an example for an intrinsic development, such as, in the European context, the elaboration of the Aristotelian system of knowledge and its subsequent transformation into modern science during the early modern period (Damerow et al. 2004). The transfer of a given system of knowledge in a process of colonization to a new natural and cultural setting may serve as an example for an extrinsic development. Intrinsic and extrinsic developments may be closely intertwined. Extrinsic (i.e., societal) contexts may be transformed into conditions for the intrinsic (i.e., cognitive) development of knowledge systems (e.g., the role of democracy for the prospering of science or the role of colonization processes for the development of biological and medical knowledge), while the intrinsic evolution of knowledge systems may become an extrinsic factor of knowledge globalization. The possibility of colonization processes, for instance, may depend on achievements of intrinsic knowledge developments, such as progress in astronomy or navigation techniques.

All knowledge traditions are local traditions in the sense that they depend, at least at their origin, on specific contexts, specific groups and specific ranges of knowledge, as well as on a specific history determining its architecture in an ultimately contingent manner. Globalization of local knowledge traditions involves intrinsic as well as extrinsic developments, potentially enhancing their social dominance, their range of application and their degree of reflexivity or, alternatively, destroying their autonomy and reducing their complexity. The globalization of local knowledge has thus to be conceptualized as a crossover phenomenon resulting from the integration of local knowledge traditions whose initial encounter depends primarily on a specific constellation of dominance, resources and knowledge potentials, that is, on an extrinsic dynamics, while their subsequent co-development is also shaped by an intrinsic dynamics.

The globalization of local knowledge is typically accompanied by a localization of globalized knowledge in the sense of the recontextualization of an alleged universal system of knowledge which may trigger its restructuration. Thus, as a rule, the implementation of globalized scientific knowledge in new contexts has not just taken the form of an application and specification, leaving its intrinsic structures unaffected, but has yielded instead a hybridization of globalized and local knowledge, changing the overall history of knowledge, even with regard to the initial constellation of dominance, resources and knowledge potentials.

1.4 A Historical Outline of the Globalization of Knowledge

This book represents a test case for the possibility of a large-scale comparative history of knowledge. Is it possible to draw general conclusions, beyond a compilation of disciplinary insights, about a subject as vast as the processes of knowledge transfer and transformation from the beginning of human history until today? To offer a definitive answer, one would obviously need many more case studies than we could assemble in this volume and an even greater effort at integrating their results. Yet, from the extensive discussions among the authors, which have accompanied the preparation of their contributions since the initial Dahlem Conference in 2007, some preliminary conclusions could be drawn which justify further research in this direction. From the perspective of the editor of this volume, some of these conclusions are summarized in the introductory surveys to the four parts of the book (chapters 3, 9, 16 and 24). These preliminary conclusions mainly aim to encourage innovative forms of cooperation that bridge both cultural and social history and also theoretically guided comparative approaches. The relation of our discussion on the recent literature on globalization is reviewed in chapter 2.

1.4.1 From Technology Transfer to the Origins of Science

Part 1 of this book explores a series of processes in the very early phases of globalization, from the transmission of practical knowledge to the emergence of science. It is normally assumed that the growth of knowledge in early history is merely an outcome of innovations, such as the development of sedentariness, the invention of new technologies including ceramic and metallurgical production, the introduction of a redistributive economy, the emergence of the state and the origin of writing. Here, we show that the history of knowledge is a layered history, where more recent knowledge builds on successive layers of older knowledge in such a way that the outcome of a knowledge production process becomes the precondition for the stability of the level of development attained. We are thus dealing with a self-referential process of knowledge generation and dissemination. For example, the invention of writing in Mesopotamia was originally a consequence of state administration. Not only did it change the conditions of the geographical transfer and historical transmission of knowledge, but it also extended the human cognitive facilities by stimulating reflection processes and the creation and articulation of previously unknown mental constructions. Eventually, writing was converted from a consequence into a precondition, not only for a particular model of state organization, but for a level of socioeconomic development depending on these novel mental constructions, from literature to science.

Science initially emerged as a mere by-product of sociocultural evolution, as a reflection on the material means of human interaction with nature outside their immediate contexts of application. Mathematics, for instance, emerged in ancient Babylonia when the material means of organizing human labor, such as accounting systems, became an object of intellectual exploration in the context of teaching

these systems to specialized scribes. Science emerged independently in different places in the ancient world. The globalization of science in the sense of an exchange of systems of theoretical knowledge across large distances, for instance within the wider Mediterranean world or East Asia, also goes back to classical antiquity. Due to economic and political circumstances, however, this exchange remained limited and episodic without the combination of accumulation and autonomous diffusion of scientific knowledge characteristic of more mature phases of globalization.

While in the polycentric world of Europe, the Near East and India, exchange did indeed take place among cultures as diverse as ancient Babylon, Egypt, Greece and India, a continuous accumulation of scientific knowledge beyond local networks, such as Hellenistic society, was prevented by a scattered urban landscape with only a few hubs of economic and epistemic trading, as well as by the scarceness and fragility of institutions dedicated to the production and transmission of such knowledge.

In contrast, such an accumulation of theoretical knowledge did take place in the relatively monocentric world of China beginning with the Qin Dynasty, resulting in a system of knowledge deeply embedded within and limited by the practice and ritual contexts of state administration and, in this form, also diffused to Japan, the Korean peninsula and South-East Asia.[17] This determining context of knowledge production and transmission would also serve for a long time to come as a strong selective filter for the appropriation of new kinds of knowledge so that, for instance, new astronomical knowledge relevant to state rituals would be continually assimilated to the traditional knowledge system, whereas the system resisted the appropriation of new technological knowledge that might have had labor-saving effects, but no immediate significance for state administration.

The strong dependence of the dynamics of the development of knowledge in antiquity on local economic, political and ideological factors was, both in the East and the West, due to the fact that the networks supporting knowledge generation and exchange were centralized in the sense of being dependent on all-important centers that constituted potential critical points of failure. While even the exchange of knowledge between the two extremes of Eurasia, which were connected by trade routes, may not be excluded, it can only have played a marginal role because of the very network of weak ties of epistemic networks in antiquity. In summary, even the ancient world was subject to a globalization of science that remained, however, episodical.

1.4.2 Knowledge as a Fellow Traveler

Part 2 of this book deals with the dissemination of knowledge in the sequel to that of power and belief structures on the Eurasian continent. It thus studies knowl-

[17] See, for example, (Schottenhammer 2007). Comparing the China Sea with Fernand Braudel's narrative of "Mediterranée," Wang Gungwu argues that "the China Sea did not have a history that was comparable to the intense exchange of peoples, goods and ideas that characterized the Mediterranean" (Wang 2008, 7–22). See chapter 11 and also the discussion in (Malkin 2011).

edge as a fellow traveler, its transmission being largely governed by an extrinsic dynamics. Yet this transmission of knowledge also involves an intrinsic dynamics, strenghtening the significance of knowledge as it proceeds, for instance, by stimulating the creation of new media and new institutions for its transmission. A special role is played by such all-encompassing belief systems as the world religions. Their self-contained and self-organizing qualities enabled them to challenge the authority of political powers, to outlast their initial reference states and to significantly contribute to a globalization of knowledge. They also offered long-lasting epistemic frameworks guiding the selection, appropriation and accumulation of knowledge. At the same time, religious systems are constantly challenged by new knowledge.

In the European case and in contrast to the case of China, the tradition of religion to challenge the authority of the state contributed to create the conditions that allowed science to challenge the authority of religion. In China, scientific knowledge received its ultimate justification from its constitutive role for the state. The role of scientific knowledge in a particular society thus depends on the dominant epistemic constellation, which is determined by shared epistemic frameworks such as religions as well as by political, economic and cultural boundary conditions. As long as scientific knowledge is merely a fellow traveler of other societal processes, its survival often depends on transient resonance effects with the dominant epistemic constellation. Only when science in turn affects the dominant epistemic constellation, as happened in early modern Europe, does it lose its ephemeral status, initiating an intrinsic dynamics of the globalization of science.

Religions have been one of the most important conveyors of the globalization of knowledge and of science in the period between antiquity and the early modern era. With the rise of Buddhism in India and of Christianity and Islam in the West (as well as Judaism after the destruction of the Second Temple), religion became decoupled from the state to a previously unparalleled degree, emerging as a source of authority separate from and potentially in conflict with that of the state, thus developing a potential for global spread (world religions). This new development set the stage for the accumulation and transmission of knowledge which, while nonetheless always extrinsically motivated, would neither be confined to local networks nor be inseparable from immediate contexts of application, and thus free to be repurposed or translated to new contexts.

The extent to which this possibility was realized remained largely contingent on the emergence of a social network that supported the production and dissemination of knowledge. Hubs in this network were typically flourishing trade or religious centers, or capital cities of large empires. Structurally speaking, an empire may be characterized by a limited number of hubs with many links and a large number of locales (in terms of network nodes) with few links, and often with only a single link to a hub. As to the longevity of knowledge accumulation within such networks, it is their high interconnectivity that prevents knowledge growth from being limited by the ephemeral fortunes of local centers, as knowledge travels

easily and is no longer dependent on a single center. In sum, traveling is a way of preserving knowledge. Empires further facilitate the wide-range diffusion of knowledge and, in particular, the integration of knowledge emerging from different hubs. But they are not the only social structures with such properties, as the global infrastructures of the world religions could and indeed did serve the same function over extended periods of time.

1.4.3 From Knowledge as a Fellow Traveler to the Globalization of Modern Science

It was only in the densely connected urban landscape of early modern Europe that a self-reinforcing mechanism connecting the production of specifically scientific knowledge with socioeconomic growth arose, driving combined globalization processes of science and economy. The combination of epistemic and economic globalization by a feedback loop with an inbuilt tendency to scale up is the hallmark of the globalization of modern science. In this period, a class of highly mobile scientist-engineers emerged who were concerned with the resolution of military and technical problems on behalf of various, mutually competing patrons (Renn 2001).

Medieval and early modern science had been able to cross political and cultural borders, also because of its use of Latin as a lingua franca. But when Latin as a scientific lingua franca became increasingly complemented by the development of scientific traditions in the vernacular, the vertical (social) mobility of science and its practitioners also increased.[18]

Also, the availability of cheap writing materials in Renaissance Europe made a huge difference for both the social and the spatial mobility of knowledge. In the past, technical knowledge had been confined to groups of specialist practitioners and separate from traditions of theoretical knowledge such as the Aristotelian tradition. The new scientist-engineers were involved with practical problems and assimilated the knowledge of practitioners; at the same time they worked within frameworks of theoretical knowledge, which caused them to reflect upon practical knowledge. This reflection led to the equilibration of practical and theoretical knowledge that gave rise to modern science.

Ultimately science is reproducible and transportable, not because of any methodological principle, but because it focuses not on ends, which tend to be more localized, but on means. In addition, it was recursively decoupled—albeit never completely—from its original contexts by an ever longer chain of representation and reflection. But the practice of science in the early modern period, as in antiquity, was initially bound to specific local contexts, such as courts or certain urban centers on which its individual practitioners depended for their support. Due to the association of science with a socioeconomic transformation process, however, it emancipated itself from its immediate contexts by creating institutions

[18]This process is studied in (Burke 2004). The importance of the simultaneous use of Latin and a vernacular language for multilingual communication is highlighted by Alix Cooper (2007).

of its own and a network of communication extending across Europe, its colonies, and even to Asia. As a consequence, science was decreasingly bound to social and geographical contexts. It no longer constituted an exceptional social phenomenon depending on favorable circumstances and was increasingly freed from immediate, context-dependent practical purposes, as was characteristic of traditional medicine or astronomy.

In the early modern period, all the patterns of the globalization of science had essentially already formed within the European network of scientific knowledge.[19] Indeed, the early modern period saw a massive diffusion of scientific knowledge within Europe, fostered by the spread of universities, academies and educational institutions, producing not just literacy, but a particular curriculum contributing to the creation of a canon of scientific disciplines.

The successful expansion of science within Europe created a model essentially followed by all later globalization processes of science, including the replication of institutional settings and canons of knowledge. The thus emerging network of scientific knowledge exhibited self-organizing behavior, as is evident in the fact that there was no central control of scientific practice, and yet scientific knowledge accumulated at an astonishing rate and traveled quickly across the scientific community.[20] The growth and mobility of scientific knowledge resulted from a network in which most scientists were in contact with only a few other scientists, but there were a few scientists who were in contact with very many scientists, acting as network hubs. This network possessed these same connectivity properties at the level of institutions sponsoring and promulgating scientific knowledge, such as courts, religious societies, the homes of wealthy patrons, universities and the newly founded scientific societies. Again, most institutions had direct relations with only a few others, but a small number of institutions were hubs with numerous direct connections. The presence of such similar structures at the levels of individual scientists and of institutions engaged in science illustrates the properties of self-similarity and scale-freeness. Positive network externalities fostered the inherent dynamics of spreading science so that the more people engaged in it, the more useful it became.

[19]Toby Huff places strong emphasis on institutional and social conditions for science, on the one hand, and its metaphysical underpinning, on the other. The latter aspect leads to rather narrow criteria for distinguishing modern science from other types of science, while the former tends to isolate the social conditions of science from the more general knowledge economy in a given society. This focus on modern science rather than a more general focus on knowledge risks neglecting the long cumulative history of the globalization of knowledge and the introduction of Eurocentric bias, giving an a priori partiality to specific cultural and social conditions prevailing in Western Europe (Huff 2011, 14). Among the favorable conditions for science, the author, following Max Weber, emphasizes the Protestant Reformation and the associated literacy.

[20]The role of the "république des lettres" is discussed in (Rüegg 1996, 20–52). Lorraine Daston distinguishes the "république des lettres" and the modern "scientific community" (Daston 2001, 151). Jakob Vogel and Ralph Jessen analyze more closely the differences between the "république des lettres" and the national character of science organization in the nineteenth century (Jessen and Vogel 2002).

From the eighteenth century, science began to be organized in well-defined disciplines, each with a canon of concepts, procedures and methods at the center of relatively stable and institutionally embedded knowledge systems. These knowledge systems had resulted from an earlier period of knowledge integration and reorganization, which led to their stabilization. This process had centered on isolated challenges, such as the challenging objects of earlier modern engineering, which now turned into the paradigmatic objects of disciplinary science. It had been a key experience of the early modern period that the world could be manipulated by recognizing its intrinsic laws. Initially, this experience was effectively limited to a few, particular fields of knowledge, such as mechanics. But it did give rise to the hope, constituting the core of the Enlightenment ideal of science, that this limitation could be overcome by the development of a universal scientific method, thus establishing scientific rationality once and for all and independently from the contigencies of local contexts.[21]

This transcendental, universalist understanding of science became a major factor in its globalization, often justifying the introduction, in a top-down manner, of a "scientific method" into domains where the cognitive prerequisites in the sense of a prior integration and stabilization of knowledge had not been established. The limitations of this approach, however, became visible even in the earliest attempts to naively transpose the principles of such pioneering sciences as mechanics to other such fields as chemistry and biology, let alone to the social domain. In the course of history, the failures of the transcendental, universalist approach to science and its implementation have contributed to the generation of numerous "anti-rationalist" movements, from Romanticism to religious fundamentalism. These failures, however, also helped to develop a non-universalist understanding of science, exposing its deeply historical nature, but also the role of local knowledge for its development.

1.4.4 The Place of Local Knowledge in the Global Community

The different consequences of the encounter between local and globalized knowledge are dealt with in Part 3 of this book. In some cases, local knowledge systems have been irrecoverably extinguished by globalization processes in rather a short time. On the other hand, there are cases in which local knowledge has been synthesized with or at least partly defended against the influences of the global community. Although local knowledge may seem to be in retreat, it continues to be relevant, even today, for mastering such primary living conditions as food production, medicine, architecture, mobility, but also for preserving cultural identity. In addition to its double function for practical and cultural purposes, it may take the form of second-order local knowledge, shaping the generation, transmission and application of knowledge in local contexts. Such meta-knowledge tends to

[21] For a comprehensive study of the Enlightenment, see (Israel 2001, 2006, 2010, 2011).

remain implicit and is sometimes only expressed in terms of social practices, such as the organization of learning processes.

Here we claim that the role of second-order local knowledge is much more central than is usually admitted. Traditional second-order local knowledge is often less affected by changes of technology, environment or new information than is first-order knowledge and is therefore less easily rendered obsolete. At the same time, new forms of second-order local knowledge may emerge from the encounter between local and globalized knowledge. Such newly emerging local second-order knowledge, however, is itself conditioned by the global history of knowledge, and in particular by the legitimacy in a given historical situation of different epistemic perspectives, one globalized, the other local. Local knowledge played a crucial role in the differential development of non-Western countries. The variability of local conditions continues to foster the diversification of knowledge, even in the presence of globalization. The impact of this diversification of the globalization of knowledge, however, remains limited unless new forms of representation become available that allow this knowledge to be shared and made useful for shaping globalization processes with an increasing awareness of their local conditions and consequences.

1.4.5 The Globalization of Modern Science

To assess the relevance of an investigation of historical processes of globalization for the present situation, Part 4 of this book is dedicated to the great challenges faced by humanity today when dealing with knowledge. These challenges are partly consequences of sociocultural evolution, such as the climate and energy challenges, and in particular, of the powerful knowledge that has accumulated during this evolution, such as the exploitation of fossil fuels. Dealing with the consequences of such unplanned, global experiments with our planetary system seems to require more knowledge than can be produced by the dominant modes of knowledge production of sociocultural evolution. Current economic and technological challenges may require in particular the development of new diffusion models in which knowledge is recognized as an explicit transferable.

One example is provided by the widely discussed need for an alternative to the current energy distribution system, which is not sustainable and will not meet future needs. Although free market economy is the only system available for regulating the global energy system, it has failed to adequately regulate the energy system since local prices largely do not reflect global costs. Alternative energy markets may regulate not only the flow of energy, taking into account knowledge about resource scarcity, but also the flow of knowledge itself in such a way that energy production and distribution is optimized.

We thus face an emergent process, socioepistemic evolution, in which the global production of ever more and increasingly diversified knowledge about humanity's interaction with nature becomes crucial for its survival. In this process, political developments do not merely shape the conditions of knowledge diffusion,

but policy-making regarding these global challenges depends critically on the generation of new knowledge and knowledge-based assessments. In Part 4, a variety of pathways toward a socioepistemic evolution are analyzed with regard to the coupling of social and political developments and the global diffusion of knowledge.

1.4.6 Socioepistemic Evolution

In conclusion, let us summarize the larger historical framework in which the globalization of science is taking place. Modern science represents the third in a series of monumental revolutions, at the same time social and epistemic, that have affected humankind since the sedentary revolution of the Neolithic. The first was the rise of the centralized state, as for instance in Mesopotamia, where technologies allowed for reflection on practical knowledge that enabled completely new methods for the organization of labor. The second was the birth of the world religions, which challenged the authority of the state and ultimately transcended the limits of the state. Modern science, in turn, came into conflict with the authority of religion. This conflict was not one of complete opposition, but one of differing intrinsic dynamics.

Religions comprised and continued to accumulate a vast amount of knowledge, integrating it into overarching worldviews that closely connected knowledge of the natural and the social worlds; at the same time religions exerted powerful control over the totality of knowledge. Modern science, while open to expropriating much of the knowledge previously controlled by religious authorities, contested not only key elements of this knowledge, but also the authority of religion to control knowledge. From the dialectics of this conflict, science gave birth to new worldviews, rivaling that of religion, and eventually to a new social order. The commonality of the three revolutions lies in the increasingly autonomous status they achieved for the production and dissemination of knowledge, and in the increasing potential for application of this knowledge to the control of society.

This series of three revolutions ultimately resulted from a cascade of nested evolutionary processes building upon the foundation of biological evolution. Sociocultural evolution began somewhat before the emergence of modern humans. The precondition for sociocultural evolution was the evolution of a rich social intelligence aimed primarily at cooperation; the biological correlate of this development is the appearance of the neocortex.[22] The central dynamics of sociocultural evolution is the transmission of material and social culture. This mechanism facilitated the transmission of knowledge between individuals, allowing humans to shape their environment and to acquire new capabilities at a rate that is many times faster than the pace of biological evolution. Acquired knowledge was thus easily transmitted across generations.

Sociocultural evolution led eventually to the emergence of the state: the first of the three revolutions. With this revolution we see, on the one hand, the creation

[22]For a recent discussion of the onset of sociocultural evolution, see (Bowles and Gintis 2011).

of means for the external representation of knowledge which not only increased the durability of knowledge, but also permitted reflection upon the knowledge represented. This resulted in new second-order knowledge. On the other hand, the new possibilities for labor organization opened up by administration practices that were dependent on media for the external representation of knowledge, led to radical material changes for individuals, further facilitating sociocultural evolution. It was especially important that new distributions of labor liberated certain individuals from work directly concerned with their survival, thus allowing them to engage in more abstract activities of knowledge production.

The emergence of the state dramatically accelerated sociocultural evolution by allowing for an increase in the production of knowledge and offering technologies, such as writing, for the transmission of that knowledge across space and time. Qualitatively new sorts of knowledge were able to develop in this context, as for example, Babylonian science or Greek philosophy. Knowledge could now spread faster, whereas before, the spread of knowledge was essentially limited to the speed of demic spread. While items of knowledge can and indeed do travel, entire systems of knowledge hardly travel during this phase, owing to their essentially local character. Moreover, the weak links between hubs of knowledge production severely impeded the travel of knowledge. Nonetheless, with this revolution we see the first major advance in the globalization of knowledge.

The next major advance came with the second revolution, the emergence of world religions, which provided the kind of efficient networks for spreading knowledge that were missing in the earlier phase. The world religions embodied much of the structures of authority and of the mechanisms for knowledge production and dissemination of the state, but whereas knowledge in the state was limited by its geographic boundaries, the packages of knowledge associated with world religions traveled more or less freely across state boundaries. The world religions in effect constituted superstructures built upon existing social orders. They challenged the authority of the state and in a number of cases states responded to this challenge; witness, for instance, the Roman persecution of Christians. In any case, religion offered a new social order greater than that of the state, but modeled on the state; thus, for instance, the concept of the Umma in Islam and the City of God in Christianity. At the same time, the world religions could adapt; for those who adopted them there was—and is—an equilibration of traditional beliefs and the beliefs constituting the new religion. While authority was merely asserted by the state (and grounded in physical force), the world religions needed to justify their authority. Thus they developed sophisticated schemes of justification and produced extensive bodies of knowledge through complex processes of dialectics. Some of these schemes and processes had their origins in earlier systems of thought that had arisen under specific local conditions, such as Hellenistic philosophy. But whereas such schemes and processes had been local, the world religions embedded them in institutions of potentially global extent. It is against the background of

these complex schemes of argument, processes of justification and elaborate bodies of knowledge—and in dialogue with them—that modern science was born.

Modern science, the third revolution, eventually gave rise to an entirely new form of evolution. Just as sociocultural evolution was grounded in biological evolution, so this new form of evolution—socioepistemic evolution—is grounded in sociocultural evolution. With each new evolutionary process in this cascade, the preceding ones eventually become dependent on the subsequent layers. Thus, the continued existence of our species in a biological sense becomes dependent on sociocultural evolution once the latter has reached a global extent, and, with the globalization of science, our survival becomes dependent on socioepistemic evolution. Socioepistemic evolution is a process even more rapid than sociocultural evolution. It is as a result of this process that our environment has changed more in the past one hundred years than in the entire period that hominids have existed. Science is a self-organizing network that inherently scales globally. It has created conditions for accelerated social evolution, including economic conditions, which favor the further development of science. Thus science actually creates the conditions for its own propagation. In socioepistemic evolution, continuity is provided by the transmission of the means of science and the material culture of which they are part. Socioepistemic evolution is an evolutionary process in its own right, which begins when knowledge production and dissemination have attained autonomy, having become ends in themselves, and when this autonomously produced knowledge has a global impact on the human condition.

The evolution of scientific knowledge itself exhibits all the dynamics characteristic of an evolutionary process that we refer to as "epistemic evolution."[23] Epistemic evolution is nested within socioepistemic evolution, constituting one of its driving forces. The exploration of the inherent potential of the means for gaining knowledge gives rise to a variety of alternatives within a knowledge system, corresponding to mutation in biological evolution. In an advanced state of its development, these variations lead to internal tensions and contradictions, resulting in the transformation or the branch of a new system; this is speciation. Differing material and cognitive contexts create ecological niches for epistemic evolution. Various forces of selection apply. Since socioepistemic evolution is ultimately grounded in biology, its greatest selective force is human survival. But this ultimate selective force is, of course, mediated through many layers of culture and society that impose diverse proximate forces of selection on epistemic evolution such as compatibility with prior knowledge, coherence and experimental verification, but also non-scientific constraints such as prestige, compatibility with non-scientific ideologies, fashions and so forth, which may differ in their effective exploitation of social intelligence or of resources within a given ecological niche of a scientific system. But whatever the details of the dynamics of socioepistemic evo-

[23]For earlier attempts to conceive the history of science as an evolutionary process, see (Hull 1988), and the first edition (1991) of (Damerow et al. 2004) which draws on (Damerow and Lefèvre 1981) and (Damerow et al. 1991).

lution may be, it is evident that its challenges for humanity can only be mastered if the conditions for epistemic evolution are optimized to deal with these challenges, providing science with both serendipity and relevance. Ignoring these challenges could lead to scholasticism, while streamlining science for specific purposes could lead to missed opportunities for innovation.

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