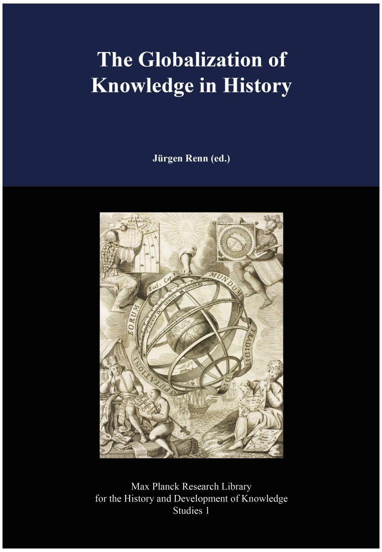
Max Planck Research Library for the History and Development of Knowledge

Studies 1

Malcolm D. Hyman and Jürgen Renn:

Survey: From Technology Transfer to the Origins of Science



In: Jürgen Renn (ed.): *The Globalization of Knowledge in History*
Online version at http://edition-open-access.de/studies/1/

ISBN 9783844222388
First published 2012 by Edition Open Access, Max Planck Institute for the History of Science under

Printed and distributed by:
Neopubli GmbH, Berlin
http://www.epubli.de/shop/buch/17018

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de

Chapter 3
Survey: From Technology Transfer to the Origins of Science

Malcolm D. Hyman and Jürgen Renn

3.1 The Beginnings of the Globalization of Knowledge

By definition, globalization processes in the contemporary era have involved geographically disparate peoples and the spread of ideas, knowledge and technologies by a variety of means over vast distances. If we pose the question as to when such processes first began, then it must be acknowledged that long-distance, indeed intercontinental, connections with an attendant spread of knowledge are as old as Homo sapiens itself. It is true, connections and contacts between distant parts of the world remained accidental and sporadic for most of human history. Only in the last century or two have such contacts taken the form of a continuous, systematic and self-reinforcing global exchange of knowledge that is turning more and more into a condition for human survival, thus launching us into a socioepistemic evolution in which change in human society is driven by the generation of knowledge.[1]

But some of the basic mechanisms of the global exchange of knowledge and its interdependence with other processes of transfer and transformation may well be recognized even in the earliest phases of human development. All of these processes are layered, in the sense that the introduction of a new process does not lead to the eclipse of earlier processes. Consequently, the globalization of knowledge is a deeply historical process in which the dynamics at any given stage depends not only on the outcome of the preceding one, but on the entire developmental trajectory back to some of its initial biological and ecological conditions. To understand the globalization of knowledge today and its role as a backbone of a future socioepistemic evolution, we therefore have to revisit this developmental trajectory from its inception. There is another, more proximate reason to do so: ignoring the role of knowledge in the development of human societies necessarily leads to inadequate descriptions; thus, for instance, the study of long-range transfer in prehistorical archaeology has been hindered by a lack of focus on knowledge.[2]

A number of global characteristics of human life developed in prehistoric times, among them the use of language, the ability to produce tools and weapons, especially artifacts made of wood and stone, metallurgic knowledge and—after

[1] For a more detailed discussion, see chapter 24.
[2] See, for example, (Renfrew and Zubrow 1994; Renfrew 2009).

the change from hunting and gathering to sedentariness—the knowledge to construct dwellings, to manage agricultural cycles of planting, harvesting and storage of cultivated plants and fruits, as well as the technologies of livestock breeding and diverse uses of domesticated animals.[3] Later came the use of symbolic means such as iconography, measurement, writing and arithmetic, eventually followed by the development of early forms of scientific knowledge. The global or potentially global character of these bodies of knowledge may result from two different kinds of historical processes and their interaction over time. Different but functionally equivalent bodies of local knowledge may merge into an integrated knowledge system as a result of cultural exchange processes. Alternatively, a useful body of local knowledge may be disseminated to or be adopted from neighboring cultures, thus spreading until it becomes a global human characteristic.

3.2 The Spread of Knowledge in the Context of the Migration of Early Humans

There is considerable evidence that humans and their close hominid kin moved out of Africa in several waves over half a million years. The earliest fossil evidence of anatomically modern humans at Omo I in Ethiopia is thought to be ca. 190–200,000 years old,[4] while the earliest evidence from the Near East (Qafzeh and Skhul Cave, Israel) is ca. 90–100,000,[5] and from Europe not more than ca. 30–25,000 years.[6] The *out of Africa* hypothesis of early modern human dispersal (probably just one of a number of waves of migration out of Africa that had been going on for over half a million years)[7] appears to be basically correct, at least with respect to Europe and Western Asia.[8] Nonetheless, the possibility that archaic Homo sapiens in East Asia evolved directly out of the local Homo erectus population cannot be ruled out completely (regional continuity model). Yet this scenario, too, would have entailed a good deal of interregional migration as areas like Australia (Adcock et al. 2001) and Siberia (Vasil'ev et al. 2002) were progressively colonized from at least 60,000 years ago. Numerous knowledge systems and technological realms as well as knowledge transfer of intercontinental, pan-Eurasian proportions can be readily documented in the pre-modern era. Even before the ascendency of modern humans, the spread of early hominids was concomitant with a spread of knowledge related to stone tool technology that led to the creation of a wide range of Upper Paleolithic tool traditions.

[3]The following survey of prehistoric developments includes a draft provided by Dan Potts, see also chapter 4.
[4]See (McDougall et al. 2005, 2008).
[5]See (Schwarcz et al. 1988; Andrews and Stringer 1989; Grün et al. 2005).
[6]See (Pereira et al. 2005; Soficaru et al. 2006, 2007).
[7]See (Templeton 2002).
[8]See (Larick and Ciochon 1996; Quintana-Murci et al. 1999).

3.3 The Spread of Agriculture and Other Early Cultural Techniques

Knowledge spread also with the later expansion of agricultural technologies relating to the domestication of cereals and animals. Intensive gathering of wheat and barley in the Fertile Crescent led eventually to agricultural practices that resulted in the genetic modification of cereals (domestication) about 10,000 years ago. Evidence for the domestication of small cattle (sheep, goats, pigs) dates this practice to ca. 8000 years ago. Within one or two millennia these agricultural advances together with the domesticated cultivars spread, through demic migration, to southeastern Europe and thence northward through Europe and eastward to Central Asia. At approximately the same time (ca. 9000 years ago) rice cultivation in north and south China gradually began to spread westward through the Indus Valley (ca. 5000–4000 years ago) to the Persian Gulf and Mesopotamia (ca. 3000 years ago).[9] Cultivars such as these were certainly never "disembodied" from the knowledge systems required for their successful cultivation (except much later when exported in bulk as commodities). Instead it was a gradual demic diffusion that brought cultures into contact, thereby introducing them to the technologies and practical knowledge of other cultures. Agricultural practices required a detailed body of practical knowledge concerning strategies for sowing, tillage, tending, harvesting and processing. With the adoption of these practices we see the shift from a hunter-gatherer to a sedentary mode of existence; with the emergence of sedentary cultures, new possibilities for the accumulation and spread of knowledge opened up.

Ceramic technology, for instance, first attested around 8500 years ago at Ganj Dareh in Iranian Luristan, may have spread westwards into Europe as part of the Neolithization process.[10] It is attested even much earlier in Eastern Asia. Ceramics have been found at early Neolithic sites in southern China (e.g., in Mioyan, Yuchanyan, Xianrendong and Diaotonghuan) in contexts dating as early as 16,000 years ago, while the earliest pottery in Japan, belonging to the Jomon culture, appeared ca. 13,000 years ago.[11] In the realm of music, specific instruments spread widely across Eurasia. The arched harp, for example, is attested iconographically at Choga Mish in southwestern Iran ca. 5400 years ago. A sign representing an arched harp appears in the Harappan or Indus Valley script over 4000 years ago and the instrument is attested in Vedic and later Buddhist sources, in Burmese art and texts, at Penjikent in Sogdiana, on the Silk Road, around 1200 years ago, and at Dunhuang in western China during the Song Dynasty (960–1279).[12] All

[9] See (Liu et al. 2007).
[10] See (Hole 1987).
[11] See (Kharakwal et al. 2004).
[12] See (Lawergren 1994).

in all, for many issues that were still controversial several years ago, the diffusion argument seems to have won the day.[13]

3.4 The Spread of Animal Husbandry and Implications for Long-Distance Transport

The diffusion of knowledge across the Eurasian landmass, however, was not confined to the gradual, overland expansion of small groups of people moving into new areas and the ensuing exposure of other groups to their technologies. The domestication of equids (*Equus asinus* and *Equus caballus*) and camelids (*Camelus bactrianus* and *Camelus dromedarius*) increased the possibility for disparate groups to communicate with each other over great distances. These transport animals, later also used for riding, constituted a new, faster means for the spread of not only goods but also knowledge. In an earlier period, precious goods such as obsidian, lapis lazuli, marine shells, ivory, copper, tin, silver, gold and electrum could be traded through a series of relays from community to community or region to region. Once transport animals became available, trade was greatly facilitated and more complex large-scale economic structures developed. The domesticated Bactrian camel (evidenced in Inner Mongolia ca. 8100 years ago) facilitated long-range Eurasian contacts three millennia or more before the historically attested Silk Road caravan trade. The Bactrian camel had spread massively westward across the central Eurasian steppes, beginning ca. 6000 years ago, reaching Syria a thousand years later, demonstrating a dramatic increase in human mobility within regions of Eurasia (Potts 2004). Arabian camel caravans were impossible until the much later domestication of the dromedary after ca. 1000 BCE (Uerpmann and Uerpmann 2002). These developments made targeted trading expeditions and military forays possible, and moreover made accessible regions hitherto inaccessible; as a result, corridor-like connections emerged, spanning an extended geographical network. Thus in this period, geographic knowledge must have increased and spread dramatically.[14]

New possibilities for maritime travel also emerged in the mid-Holocene. Evidence points to the existence of early watercraft in the Persian Gulf ca. 8000 years ago. Nor was coastal sailing the only option for early mariners. The discovery of banana phytoliths in the interior of Africa at the site of Munsa (Uganda) in contexts some 5000–6000 years old—together with the absence of banana at any intervening sites in Southeast Asia, India or the Arabian peninsula—strongly suggests that the banana was transported by sea from its origin in Papua New Guinea (Lejju et al. 2006). Until recently, most scholars did not believe the banana had been introduced into Africa until the first millennium CE. Intensive

[13] See chapter 4, in particular, section 4.2. Potts emphasizes that an examination of the spread of the technologies underlying the production of certain artifacts offers an alternative to the study of the spread of the end products themselves.

[14] For further discussion of such corridor-like connections, see the survey of Part 3, chapter 9.

banana cultivation in New Guinea is now known to have begun ca. 6500 to 7000 years ago (Denham et al. 2003). Thus trans-Indian Ocean sailing was a reality at least 6000 years ago. Some 1500 years later, long-distance sailing between India, southeastern Arabia and Mesopotamia was becoming routine.[15]

By the end of the fourth millennium, Eurasia was well connected by trade routes running along east-west and north-south axes. These routes allowed for economic, technological and epistemic interchange. In contrast, in the Americas similar processes took place, such as the domestication of plants and animals, sedentariness, the development of technology such as ceramics and metallurgy and ultimately even urbanism and writing, but the extent to which these developments were exchanged was limited. Greater geographical obstacles constituted fundamental limits, impeding long trade routes. The climatic diversity resulting from the north-south axis of the continents limited zones of population contact as well as the transfer of agricultural achievements.[16]

3.5 The Spread of the Proto-Indo-European Language as an Example of Knowledge Disseminated Through Language

Knowledge also spread with language, as language spreads with migration, conquest and trade. Before 3000 BCE, speakers of a Proto-Indo-European language began to spread throughout Eurasia.[17] By the fifth century CE, we have firm evidence that descendants of this language ranged from Ireland in the West to the Xinjiang province of China in the East. The Proto-Indo-European language was transmitted in part by demic migrations, but also through being adopted, apparently as a prestige language, by indigenous alloglottic populations. With the language were transmitted the social structures, religion, legal institutions, literary tradition, and medical and architectural knowledge of Proto-Indo-European society. This knowledge and these institutions were transmitted in large part by a technology of oral poetic composition that built upon and extended the potentials inherent in spoken language; this is probably the first mnemonic technology and almost certainly predates writing.[18] Formulaic verbal expressions (e.g., legal formulae) were a crucial vehicle for the transmission of the symbolic and technological knowledge of Proto-Indo-European culture; these could be embedded in traditional oral poetry (as exemplified by the Homeric epics). Such formulaic expressions can be reconstructed from literature of the descendant languages of Indo-European, such as Hittite, Vedic Sanskrit, Ancient Greek and Latin.

Linguistic reconstructions attest a culture characterized by an aristocratic class concerned with religious and military affairs; an organic conception of com-

[15] See (Cleuziou and Tosi 1994; Potts 1995), see also (Meyer et al. 1991) for evidence of long-distance sailing between the environs of Zanzibar to Tell Asmar in northeastern Iraq. For an overview of "the maritime Silk Road," see (Ptak 2007).
[16] See (Diamond 1998).
[17] See (Cardona et al. 1970; Haudry 1981; Mallory and Adams 2006).
[18] See (Rubin 1995; Watkins 1995).

munity in which the structures of the whole society mirrored those of the individual family; a public law based on contract; the practice of divination; and a tripartition of medicine into surgery, pharmacotherapy and healing by spells or incantations.[19] Religion played a key role in the transmission of knowledge, and it has been argued that with rituals (and associated verbal recitations), specific geometrical and architectural knowledge—needed to construct ritual altars—traveled from Central Asia to India and Greece.[20] It is, however, still debated whether Indo-European language and culture spread by means of agricultural diffusion, or by military expansion with a mostly nomadic form of economy. As a matter of fact, military expansion is also often accompanied by the diffusion of technologies, military and others and slave trade, as well as enslavement, in the wake of wars may serve the diffusion of crafts and expertise.

3.6 Urbanization in Babylonia and the Invention of Writing

In the fourth millennium, we see the beginning of large-scale settlements in Babylonia. At this time we also see, not coincidentally, the development of writing, which in time will lead to a dramatic increase in the durability and transportability of knowledge.[21] The urbanization processes centered in Uruk and Susa, which reached their acme in the middle of the fourth millennium, led to the development of new cultural products, such as architecture, cylinder seals (as opposed to stamp seals), the mass production of pottery, as well as proto-writing and proto-arithmetic.[22] The precondition of both the seals and of writing is the human capability to represent experiences symbolically, a faculty that developed at least 30,000 years ago. Writing appeared around 3300 BCE in Mesopotamia; the largest group of texts is from Uruk, but other text groups have been found in northern Babylonia. A group of texts found in an Egyptian grave in 1989 may be contemporaneous with the beginning of writing in Mesopotamia, but most likely these texts are somewhat later.[23] The earliest documents are clay tablets with numerical notations and sealings that likely indicated institutional contexts. By ca. 3300 BCE, a system known as archaic cuneiform or proto-cuneiform had developed. The vast majority of proto-cuneiform tablets were instruments for representing practices of accounting and administration associated with the new urban culture. This early writing was hardly, and possibly not at all, related to the structure of spoken language. It thus did not represent the meaning of words or sentences,

[19] See (Benveniste 1945, 1969).
[20] See (Staal 1999).
[21] See (Nissen et al. 1993; Englund 1998; Woods 2010). See also chapters 5 and 6. The following is based in part on comments by Jens Braarvig.
[22] According to Damerow, local developments of writing and arithmetic have interacted in various ways over the course of history. In the case of arithmetic, the end result was a unified system of arithmetical notation and calculational methods. In the case of writing, historical globalization processes have spread writing all over the world, but have neither led to a unification of languages nor of writing systems (see chapter 6, section 6.1).
[23] For an overview, see (Stauder 2010).

nor did it reflect grammatical structures of language, but rather meanings related to specific mental models of societal practices such as accounting. It was on this basis, however, that the second invention of writing, that of writing as a universal means of codifying language, eventually took place.

Traditional studies have presented writing as a technology, the purpose of which was to record spoken utterances with fidelity. This began with pictograms and inevitably moved toward full alphabetic writing.[24] Recent literacy studies, associated above all with Jack Goody and Ian Watt (1963; 1986), conceived of writing, in the words of Walter J. Ong (1986), as a technology that restructures thought. In both lines of research we see emphasized, on the one hand, the form of writing, and on the other, the consequences of writing. Both downplay the diverse purposes of writing, the varying social needs that writing addressed in ancient cultures and the emic perspective of how practitioners (professional scribes, lay readers and so forth) themselves conceptualized writing.[25]

Writing arose in Mesopotamia, as we have emphasized, and for some time it remained closely tied to practices of politico-economic administration. In Egypt, writing was more closely tied to the display of monumental inscriptions which served to legitimate the authority of priests and rulers. Here, the aesthetic aspect of inscription was foregrounded and writing was closely linked to artistic and architectural purposes. From these beginnings, writing began to be put to more and more uses: epistolography, historiography, the recording of empirical observations, *belles lettres*. With changes in function, adaptation to new societies with varying socioeconomic structures, and adoption by different classes, writing took on new forms, as in the transformation of hieroglyphic into hieratic and demotic, the evolution of a predominantly logographic Sumerian cuneiform into a predominantly syllabic Akkadian cuneiform, and in the development of the West Semitic writing systems.

From the perspective of writing as an external representation of knowledge, it is necessary to compare the various ways in which writing encodes knowledge. The earliest writing was primarily, if not exclusively, non-glottographic, that is, its structure was not derived from that of spoken language (Hyman 2006). Later, we find writing exhibiting a closer dependence on spoken language, but apparently still sometimes encoding event structure more or less directly, rather than linguistic structure. Thus we often find indications of actor, action and object, while grammatical morphemes are absent or underrepresented, and modality, for instance, lacks any exponentiation whatsoever.

Writing also plays a key role in the standardization or canonization of knowledge: in standardizing systems of classification (e.g., Sumerian lexical lists), legal codes (e.g., Hammurabi's Code, Deuteronomy, the XII Tables), calculation techniques (e.g., mathematical tablets), and literary texts (e.g., the vulgate of the Homeric epics). Likewise writing, in fixing certain knowledge (e.g., astronomical

[24] See, for example, the work of Ignace J. Gelb (1952, 1963).

[25] For more recent studies, see (Halverson 1992) and (Collins and Blot 2003, in particular, 9–33).

diaries), allows reflection on that knowledge and the generation of more abstract theories or models (such as arose in Babylonian or Greek science).[26]

Concomitant with the invention and use of writing, a number of fields of knowledge were accordingly facilitated and developed during the third millennium BCE to serve the state—the developing bureaucracy of administration, military activities—and trade and religion, viz. accounting and lists of resources, metrology, mathematics, medicine, formalized law, lexicography, historiography and poetic literature both inside and outside of the religious sphere, not to mention the tremendous activities concerned with "scientific" divination.[27] With the advent of writing, trade and the exchange of goods on a larger scale were also developed, accompanied by written contracts, agreements and systematic and regulated forms of communication, also developing into multilingual formats.

3.7 Multilingualism, Language Contact and the Spread of Knowledge

The ancient Near East is not only the site of the earliest known writing, it is also the first location for which we possess evidence of a multilingual culture. From the beginnings of Sumerian literature, there is already evidence (lexical and onomastic) for a diverse multilingual society in which there were not only speakers of Sumerian, but also of languages belonging to the Semitic family. Incantation texts in both Sumerian and Semitic versions existed as early as the Fara period (ca. 2500 BCE) and suggest a culture in which Sumerian was a "foreign" language for many scribes. Starting in the seventeenth and eighteenth centuries, we find Old Babylonian Grammatical Texts in the form of Sumero-Akkadian and Akkado-Sumerian glossaries. These texts not only bear witness to a culture that explicitly recognizes its own multilingualism, but also constitute the first historical moment at which humans began to engage in a significant reflection on their own language(s)—at this moment metalinguistic knowledge was born. That Sumerian already existed in a bilingual culture as early as the Fara period is also suggested by the fact that many of the scribes appearing in the colophons in the Abu Salabikh texts from the Fara period had Semitic names, even though otherwise the texts themselves never include Semitic linguistic forms.[28]

Ancient multilingualism is further attested by the culture of scribes working with several languages. Additional evidence is found in the frequency of translation, for example, from Akkadian to Hittite and Hurrian, from Hurrian to Hittite. We find, for example, the Gilgamesh Epic in a number of translations. Akkadian was used as a diplomatic language and lingua franca for the Hittites and Ugarit royals to communicate with their Egyptian counterparts. This amply demonstrates

[26] See chapters 6, 7 and 8.

[27] See chapter 7. A standard reference is (Neugebauer 1957). For the historical context of the emergence of mathematics, see (Robson 2008; Damerow 2010).

[28] See (Biggs 1966; Biggs and Postgate 1975; Cagni 1981; Krebernik 1984, 2007). For a general overview, including all relevant literature, see (Krebernik 2007).

how states chose to communicate with each other in a third standard language as early as the second millennium BCE. The Persian Empire, and later also the Aśokan Empire in India, used multilingual media to communicate their decrees and ideas to their multilingual empires, remains of which we find in the Behistun inscription and the famous inscriptions of Aśoka in Maghadi, Aramaic and Greek, where Aśoka promulgates religious tolerance to both his own empire and to his neighbors. As recent research in anthropology, linguistics and psychology has amply demonstrated, multilingualism is the norm in human culture. The history of civilization is largely a history of peoples who, to varying degrees, have negotiated a multilingual environment, created by factors such as population movements and expansions, exogamy and economic insufficiency.

3.8 The Spread of Babylonian Culture

The knowledge connected with Babylonian cultural products, including writing, spread over large areas of the Near East, from the Levant to Iran. It is not always clear to what extent such techniques were adopted by local cultures with long-term effects, or whether they remained merely a superficial contact phenomenon.[29] Following the Uruk period (3400–3000 BCE), a fragmentation of societies can be observed, a phenomenon that can be attributed to ecological and demographic changes. Common cultural traits, however, such as the technique of writing, were preserved and even further developed.[30]

Around the middle of the third millennium we see a major interregional contact sphere that must have promoted considerable cultural exchange in the interconnected societies. Even before the emergence of the first contemporaneous empires, during the period of feuding "city states," cultural technologies such as writing had already spread from southern Babylonia to the Levant (i.e., Ebla). Writing had also undergone significant changes in the meantime and was now phonetically representing the structure of spoken language (Krebernik 2007). As early as 2500 BCE, we find written collections of proverbial sayings (Alster 2005, in particular, 31–220). Long-term record keeping is also attested for the first time. The Old Akkadian centralized state (ca. 2350–2200 BCE), incorporating various traits of its predecessors, attests to the emergence of newly ordered institutions (kingship, standing armies, palace administration) and significant processes of standardization in writing, metrology and other areas. During the subsequent Ur III period (ca. 2100–2000 BCE), known for its enormous administration, we find the first traces of new forms of written literature and historiography, which built

[29] Cancik-Kirschbaum emphasizes the need for a host of techniques to access the knowledge stored in writing (chapter 5, section 5.1). She argues that writing should not be conceived as automatically fostering the globalization of knowledge, since it requires a high degree of specialization and practices that are localized both in space and time (section 5.4).
[30] For the Uruk period, see (Englund 1998).

to a large extent on older traditions and established a framework for the cultural identities of ensuing societies.[31]

The organization of society underwent tremendous changes in the following periods. In addition to the temples, we find a largely independent state administration, as well as a tendency toward increased individualization and privatization, including the possibility of private property and individual economic ventures. As far back as the Old Assyrian (ca. 1950–1750 BCE) and Old Babylonian (ca. 1850–1600 BCE) periods, we already observe a reduced number of cuneiform signs in use, which facilitated everyday communication, attested in letters and administrative documents. This process, which can be thought of as a "democratization of writing," is paralleled by the slightly later invention of alphabetic scripts in the Levant.[32]

New forms of written knowledge that appear in this period include: grammatical texts; divination texts; lists, which will eventually evolve into specialized genres such as star-lists; historiographical texts, such as copies of Old Akkadian royal inscriptions; the first Akkadian literary corpus; private legal documents; "mathematical" texts; healing texts; astronomical texts; and so on. In this period, we also find a number of multilingual lexical lists, documenting the written and formalized multilingualism in the area, which throughout history is characterized by great language diversity. Some of these texts had precursors, but the level of systematization attempted, and in part achieved, during this period sets them clearly apart from earlier texts. A major part of this literature was transmitted and preserved in schools linked to the temple rather than to the palace administration (which represented the actual seat of power during this period). For the first time we can observe a clear knowledge dichotomy between state institutions and religious institutions. This opposition became crucial in the creation and transmission of knowledge for the remainder of Mesopotamian history and persists to the present day.[33]

The canonization of Babylonian literature took place to a large extent during the Kassite Dynasty (ca. 1600–1300 BCE) (Lambert 1957). We can interpret this process as a conscious attempt to incorporate existing patterns of knowledge. This knowledge spread far beyond the borders of Mesopotamia to Anatolia, Iran and even to some extent to Egypt, influencing local knowledge traditions. As Mesopotamia became an international power from the twelfth century BCE onwards, the collecting of knowledge was increased and became a thoroughly systematic enterprise. The attempt to organize knowledge systematically led to the accumulation of vast amounts of knowledge, particularly in the areas of astronomy

[31] For the early dynastic period, see (Bauer 1998; Krebernik 1998) and for the Ur III period (Sallaberger 1999).

[32] For the Old Assyrian and Old Babylonian periods, see (Charpin et al. 2004; Veenhof and Eidem 2008).

[33] For the Old Akkadian period, see (Westenholz 1999). Further discussion can be found in the survey of Part 2 (chapter 9).

and meteorology.[34] In this period, Akkadian was a lingua franca and a powerful instrument of the diffusion of knowledge, as it was used as a diplomatic language as well.

Writing spread beyond Mesopotamia, and this spread constituted the precondition for the diffusion of other kinds of knowledge from Mesopotamia. Minoan writing appeared in the context of the palace economy on Crete around the turn of the third to the second millennium BCE. Two different systems of writing existed, both undeciphered: the so-called Cretan hieroglyphs and the syllabic Linear A script. These systems almost certainly are the result of stimulus diffusion from Mesopotamia. Writing spread subsequently to the Greek mainland, where it is seen in the Mycenaean culture (which emerged around 1600 BCE); at this time, the Linear A script is replaced by Linear B (ca. 1500 BCE), a largely syllabic script (also including some logograms) for encoding the Greek language. Linear B was used in the administration of the complex agricultural economy of Mycenaean civilization, with tablets from Knossos and Pylos documenting taxes, deliveries of goods, rations for workers and other such administrative practices. By the end of the second millennium the Mycenaean civilization had collapsed, for reasons that still remain unclear, and the Linear B script was no longer used.[35]

On the island of Cyprus, an undeciphered script termed Cypro-Minoan (usually interpreted as having three varieties) was employed in the second half of the second millennium. This script apparently derives from Linear A and is the source of the Cypriot syllabary, which came into use toward the end of the first millennium and remained in use well into the period when Greek alphabetic writing was employed on the mainland, being replaced entirely by the Greek alphabet only in the fourth century BCE.

Current consensus dates the Greek alphabet to around the ninth century BCE.[36] The alphabet was modeled upon that of the Phoenicians. But whereas Phoenician and West Semitic alphabets in general possessed characters only for consonants, the Greek script adapted certain Phoenician semi-vowel characters (known as *matres lectionis*, for example, w, y) as vowels. Phoenician/Greek contact was extensive in the ninth century, and it has been argued that the alphabet shows signs of influence from the Cypriot syllabary, thus suggesting perhaps an origin in Cyprus (where there existed a significant Phoenician presence). A West Greek alphabet constituted the model for the creation of the Etruscan (before 700 BCE), the Latin (seventh century BCE) and Cyrillic (ca. ninth century CE) alphabets. Latin and Cyrillic eventually became two of the most frequently used scripts in the world.

[34] See chapter 7.

[35] For the spread of writing from Mesopotamia, see (Sasson 1995; Houston 2004; Baines et al. 2008).

[36] For a discussion of the Greek alphabet, see (Woodard 1997; Krebernik 2007a).

3.9 Greek Science and Its Counterparts

Knowledge of Mesopotamian and Egyptian astronomy, cosmology, medicine and arithmetic diffused gradually into the Greek world. Earlier it had diffused into the Persian Empire in the wake of its conquests, a diffusion that in turn influenced the Greeks.[37] We see reflections of this knowledge back around the eighth century in the poet Hesiod, who was influenced by the Phoenican and Hittite cultural traditions and to a lesser degree even earlier in oral Homeric poetry. But it is in Miletus, in Asia Minor, where we find in the late seventh and sixth centuries BCE the first speculative writings in Greek concerning natural philosophy. As a trade city, Miletus was well connected to the developed literate societies of the Near East and thus open to the import of Near Eastern knowledge traditions. Hippocrates, generally considered the founding figure of Greek medicine, came from the island of Cos, only a short distance from Caria, part of the Achaemenid Persian Empire, which also embraced the ancient cultures of the Near East. In this empire, stretching from Egypt to India, Aramaic was the lingua franca. Thus Greek medicine emerged in a multiethnic, multilingual context, in which Near Eastern knowledge concerning healing would certainly have been known.[38]

While Babylonian texts conveyed primarily first-order knowledge, such as astronomical and meteorological observations or particular medical techniques, Greek science turned in a more theoretical direction and authors presented a great amount of second-order knowledge, such as predictive models or methodological reflections that constituted, at the same time, knowledge about observed regularities and knowledge about this knowledge, in particular about its production and validity. This is not to say that the Babylonians did not produce second-order knowledge, but such knowledge is scarcely found in their texts. Possibly the strong state and religious institutional contexts in which Babylonian knowledge was produced allowed for a considerable background of shared second-order knowledge that simply did not need to be documented.[39] In any case, although the Greeks came to acquire Babylonian first-order knowledge in areas such as astronomy, Greek thinkers engaged in new reflection concerning this knowledge and generated the distinctive second-order knowledge that was the hallmark of Greek science, for mathematics as well as for medicine.[40] In fact, the medical theory of four humors may well be considered as the same kind of second-order knowledge as Pythagorean mathematics, with humoral theory offering a unified formula to explain diverse medical data.

Although in Greece, writing constituted an important precondition for the extensive accumulation of second-order knowledge, writing is evidently not a nec-

[37] See (Ray and Potts 2007).
[38] See chapter 8.
[39] Note, however, that the long-term comparison of astronomical observations performed at distant places and at distant times in Babylonia required a control of the meaning of the terms used to describe the recorded events, as emphasized by Graßhoff (chapter 7, section 7.2).
[40] See chapter 8.

essary condition for such an accumulation. In early India, a purely oral culture, reflection upon the sacred Vedas, facilitated by elaborate mnemonic techniques, allowed for the generation of extensive second-order knowledge, best illustrated by the fifth-century grammar of Pāṇini, which consists of an elaborate system of approximately eight thousand rules expressed in highly abbreviated sūtra form that allow for the generation of virtually all word forms of the Sanskrit language.[41]

The spread of Greek science, including natural philosophy, medicine, mathematics and astronomy, can be summed up in five major phases, although knowledge of Greek science traveled sporadically via other routes, resurfacing in many places.[42] In the first phase, science, which began in Asia Minor and Ionia, is relocated to Athens, as the power, wealth and prestige of that city increases. The second phase, which takes place during the Hellenistic period, involves the spread of science to major international hubs, especially Alexandria, Byzantium and Rome. The third phase comprises first the Syriac, the Persian and then the Arabic translation movements.[43] In the fourth phase, Greek science reenters the Latin West, partly via translations from Greek into Latin, partly via Arabic translations, often then in turn translated into Latin. The fifth phase is the recovery of scientific texts in the Greek original by the humanists and subsequent appearance of numerous commentaries both in Latin and in the vernaculars.[44]

In Greece, traditions of natural philosophy and science initially emerged within a polycentric urban context with limited institutionalization before the Hellenistic period. The growth of scientific knowledge was largely sporadic, determined by the interests of a small number of individuals, despite attempts at systematization, such as those by Aristotle and his Peripatetic successors. The institutionalization of science and an attempt at systematic accumulation of knowledge began in the Hellenistic age, but was limited by the dependence on a few large hubs that were not part of a robust network and which constituted critical points of failure (witness the destruction of the library at Alexandria).[45] Nonetheless, Hellenistic science was able to make significant advances in certain areas, such as astronomy, as a consequence of the fact that the Hellenistic world now included Babylonia, and hence Greek thinkers had direct access to Babylonian texts and the knowledge of Babylonian practitioners. In Rome, there was substantial development of new second-order knowledge, especially of a technological variety, but this knowledge was deeply embedded in institutions such as the Roman army, and much of it was not written down. This institutional embeddedness of sophisticated second-order engineering knowledge, that is, generalized knowledge generated from reflection on accumulated practical experiences, together with a consequent lack of motivation to document the knowledge, paralleled the situation earlier in the Persian Empire and earlier still in Babylonia. Roman encyclopedists such as Pliny did, however,

[41] See (Scharf and Hyman 2012).
[42] For an overview focusing on mathematics, see (Szabó 1978).
[43] See also the discussion in Part 2 of this volume.
[44] For an exemplary longitudinal study, see (Renn and Damerow 2012).
[45] For an overview, see (Russo 2004).

assemble a considerable amount of Greek knowledge, as well as knowledge from other sources, and enable the transmission of this knowledge through the European Middle Ages. The encyclopedists, however, were in general indiscriminate with respect to the quality of their sources and presented knowledge in a largely unsystematic fashion.[46]

Greek science failed to develop further as a consequence of the fact that there was no social network sufficiently robust to preserve it.[47] Nonetheless, much of the knowledge, both first and second-order, was preserved as a result of the technology of writing, although it must be noted that the lack of durability of the writing materials necessitated the continual recopying of texts—an activity that required extrinsic motivation. Still, Greek science has been preserved, at least in part, to the present day, and practices of Greek science continued, although in piecemeal fashion, in Rome, Persia, Byzantium, Arabia and Europe, without any complete break. There was, however, little accumulation of knowledge and addition to the body of Greek knowledge before the Islamic period. In general, social conditions were such that a stable and self-perpetuating science did not emerge until early modern Europe. It is telling that Greek science had to be rediscovered so many times; that there were so many renaissances. As we shall see in Part 2, each of them exposed science to a new level of globalization, integrating it with knowledge traditions of other origins.

Science involving second-order knowledge documented in writing emerged in China at about the same time as in Europe, and in a similar social context that was characterized by competing urban centers and competing philosophical schools, such as Confucianists, Sophists and Mohists.[48] Only in the latter school did knowledge about the natural world and methods for justifying such knowledge play a prominent role. The conditions for transmitting this knowledge in China, however, differed from those in western Eurasia. With the emergence of centralized control in China under the Qin Dynasty from 221 BCE, a state-sponsored neo-Confucianist hegemony effectively prevented any philosophical heterodoxy. As a result, in China there was not even the punctuated tradition of the ancient scientific writings that took place in Europe. Thus it appears that scientific knowledge is more effectively preserved by distribution than by centralization. But when surveying the historical and geographic spread of scientific knowledge, it should not be overlooked that, whatever its fate, there is continual evolution of all other kinds of knowledge, so that a rediscovery always constitutes in effect a spoliation, a placing of older knowledge into a completely new context. When Greek science was appropriated in early modern Europe, so much had changed in the meantime—and, notably the technology of writing had diffused, diversified and been

[46] See (Thorndike 1923), see also (Collison 1964).

[47] For a study of Greek culture in terms of network analysis, see (Malkin 2011).

[48] See chapter 11; see also (Renn and Schemmel 2006). A standard reference is (Needham 1988). For a comparative assessement of Greek and Chinese science, see the work of Lloyd, in particular (Lloyd 1996, 2002).

altered by the new technology of printing—that instead of Greek science being reborn, what was born was modern science.

3.10 Interpreting Early History with the Help of a Typology of Knowledge

To approach this historical material systematically, it is necessary to focus on knowledge, even where the archeological record gives us only artifacts.[49] Thus, for instance, a narrow approach that ignores knowledge in the archeological study of metallurgy or ceramics may fail to recognize that apparently different products were created with the same technology, and thus the same knowledge. Moreover, it is not sufficient to treat knowledge as homogeneous, but necessary rather to recognize that knowledge is of radically different types. Otherwise one runs the risk of ascribing anachronistically the reflexivity, distributivity and systematicity of our knowledge to the knowledge of individuals or groups in a particular historical situation. As explained in the introduction, reflexivity characterizes the degree to which knowledge arises from reflection upon, and abstraction from, other knowledge; it ranges from intuitive knowledge to higher-order knowledge, such as scientific knowledge. Distributivity characterizes the extent to which knowledge is shared; it ranges from individual knowledge to globalized knowledge. Systematicity characterizes the degree to which knowledge complexes are integrated and internally organized; whether we deal with packages or systems of knowledge.

Taking these dimensions into account is particularly crucial when assessing the emergence of higher-order forms of knowledge, such as writing, arithmetic and science. Scholars once assumed that the earliest writing must represent language, because they falsely assumed that writing is a context-free, universal means for representing language.[50] In other words, they failed to recognize that these attributes that apply generally to writing today arose from reflection upon the operations made possible by the earliest writing, which was a specific technology associated with particular administrative processes, and which was used only by a small number of scribes who shared a large complex of practical knowledge. Similarly, scholars erred in inferring that the Babylonians knew the Pythagorean theorem from the evidence that they performed certain arithmetic operations that produced results identical to those that we would achieve by applying the Pythagorean theorem.[51] This error arose from the failure to appreciate that the Pythagorean theorem was the consequence of reflection upon operations of this sort and that the type of systematicity achieved in Greek mathematics was a property of Babylonian mathematics as well. A closer examination of the practices of Babylonian mathematics indeed shows that the arithmetic operations associated with computing the area of a triangle were part of a quite different knowledge system. But whereas Eu-

[49]This argument has been emphasized in (Renfrew and Zubrow 1994; Renfrew 2009).
[50]See, also for the following section, chapters 5 and 6.
[51]See (Damerow 2001).

clidean mathematics is a tightly interwoven deductive system motivated by formal procedures of justification, Babylonian mathematics is essentially a looser system of heuristic procedures.

It is also necessary to employ a fine-grained typology of knowledge if one is to study its transfer. Thus until modern science is globalized, becoming a dominant means by which knowledge is transmitted, first-order knowledge travels far more easily than second-order knowledge. Hence Greek astronomers were able to take over the copious astronomical observations (first-order knowledge) of the Babylonians, but from these they constructed their own astronomical theories (second-order knowledge). Babylonian astronomy, inasmuch as it was a system comprising first- and second-order knowledge, was deeply embedded within state and religious institutions that were unique to Babylonian society; thus it could not be adopted wholesale by the Greeks, but rather served as source of individual data constituting first-order knowledge.[52] Ultimately, a typology of knowledge is needed for any account of the history of knowledge that aspires to an explanation of emergent phenomena, such as the rise of science, avoiding teleological fictions that imagine history as inexorably leading to the present-day situation.

3.11 From Practical via Symbolic to Scientific Knowledge

In the early phase of technology transfer, what is transferred is mostly practical knowledge and never technological knowledge proper, as the latter requires representations that enable reflection, which were unavailable in prehistory. Practical knowledge traveled through demic movement and population contacts. Even back in the Neolithic, practical knowledge relating to agriculture reached a regional degree of distributivity. Symbolic knowledge was always available to Homo sapiens in the form of spoken language, but only with the symbolic revolution of the Upper Paleolithic was knowledge symbolically represented in durable media. The technology of writing, which came into being with the creation of the centrally administered state, greatly expanded the potential of symbolic representation by allowing for complex and formal systems of interrelated symbols that could reliably represent knowledge of complex situations. As writing came to be associated with spoken language, the integration of the two symbolic systems made possible the durable and external representation of any sort of knowledge, and radically decreased the degree to which writing was bound to a particular context. With the existence of Babylonian “mathematical” tablets, on which standard operations are performed with unrealistically large numeric parameters, we see a form of exploratory arithmetic knowledge, demonstrating that arithmetic is becoming less context-bound and more autonomous.[53] Such exploratory knowledge constituted scientific knowledge in the sense of higher-order knowledge resulting from reflecting on experiences with the material world. Science in fact emerged when the

[52] See chapters 7 and 8.
[53] See chapter 6.

means for mastering the material world, be they accounting systems or mechanical instruments, were explored for the sake of gaining knowledge, independent of their practical ends.[54]

Originally writing had only a local distributivity, but with time writing as well as arithmetic spread to a regional extent and eventually became globalized.[55] Writing was the technology that allowed the Babylonians to record their first-order knowledge of the physical world and permitted the transmission of this knowledge to the Greeks.[56] The Greeks, inspired in part by knowledge transmitted from Babylonia and elsewhere, constructed theories of cosmology, mathematics, astronomy, medicine and philosophy that comprised scientific knowledge. These complex systems of scientific knowledge exhibited a hitherto unprecedented degree of systematicity. The distributivity of this knowledge was limited to the region of the (expanding) Greek world, but the fact that these scientific systems were written down allowed their transmission to later cultures, stimulating the creation of new scientific knowledge, and ultimately a scientific revolution that eventually rendered science truly global.

3.12 Knowledge Representations in Early History

Just as it is useful to distinguish between different types of knowledge, it is important, for a historical account of its development, to take into account the different forms of representation and their specific repercussions on the structure and spread of knowledge. We therefore first look at some fundamental properties of external representations, that is, their portability, their durability and their reproducibility. Then we consider the opportunities and limitations of early writing. Finally, we turn to some examples from different historical periods of the implications of different forms of representations of knowledge, ranging from first-order knowledge to mental models.

As explained in the introduction, knowledge of any type is always bound to a particular representation, either internal (i.e., cognitive), or external (i.e., in the world). The form of representation always has implications for the structure of knowledge, for the operations that can be performed on the represented knowledge, and for its potential for transmission. External representations of knowledge make possible reflection upon the knowledge represented, which leads to new higher-order knowledge.[57] In fact, much individual knowledge is acquired from shared knowledge that has an external representation. Once knowledge is represented externally, it is subject to transfer in a knowledge economy. Particular knowledge representation technologies shape this economy in different ways since these technologies vary along a set of economic dimensions. Some dimensions that

[54]See (Damerow and Lefèvre 1981; Damerow 1998).
[55]See chapter 5.
[56]See chapters 7 and 8.
[57]See (Damerow 1996).

are important for the transmission of knowledge are portability (can the representation travel, and if so, how fast?), durability (how lasting is a representation?) and reproducibility (how easily can a representation be copied?).

In early technology transmission, the technological artifacts themselves constitute external representations of knowledge.[58] In the case of stimulus diffusion, the artifacts are the primary or only means of transmission. Even in the case where technology is taught, however, the knowledge externally represented in the artifact is of importance. With the Upper Paleolithic symbolic revolution, the first external representations specifically intended to represent knowledge come into being. Formulaic verbal expressions (e.g., legal formulae) are a crucial vehicle for the transmission of the symbolic and technological knowledge of preliterate cultures, such as the Proto-Indo-European culture discussed in section 3.5.

Writing constituted the first external representation of knowledge that was governed by formal semiotic rules.[59] In principle, writing was highly suited to travel, since it was portable, durable and reproducible. The extreme context-dependence of the earliest writing, however, made it difficult for writing to move beyond the particular institutional context in which it was embedded. As writing came to represent structures of spoken language and became increasingly phonetic, its context-dependence decreased and it began to spread widely. Over time, writing came to be employed in an increasing number of text genres, some having a parallel in spoken language and some made possible only by the technology of writing. Media of writing varied, with the clay tablet predominating in Mesopotamia, and papyrus important in Egypt and Greece. These media had important implications for the durability of the knowledge represented.

In Babylonian science, while first-order knowledge was represented in writing, second-order knowledge was represented mainly in institutions and was thus less portable. Greek science represented both first- and second-order knowledge in writing, thus lending portability and durability to its second-order knowledge.[60] Knowledge of technology often was not sufficiently represented in writing such that the knowledge could not travel without the technological artifacts themselves, which functioned as representations of additional knowledge. Moreover, the practical knowledge of practitioners was often not written, with the consequence that it was lost. Artifacts such as the balance and the gnomon were constructed primarily by means of practical knowledge, but reflection upon these objects led to a higher-order knowledge, with reflection upon the balance and lever, for instance, leading to the balance-lever mental model, which could be applied to such apparently different objects as the oar of a boat.[61] The emergence of specialized forms of writing of a diagrammatic nature allowed knowledge of certain technologies to travel in the absence of the technological artifacts. A striking early form of the diagram is

[58] See chapter 4.
[59] See chapters 5 and 6.
[60] See chapters 7 and 8.
[61] See (Renn and Damerow 2007, 2012).

found in Babylonian field plans, which encoded, among other knowledge, knowledge about the geometric computation of areas.[62] There are also both Babylonian and Greek maps which are the external representations corresponding to internal mental models of space. A significant innovation in Greek mathematics was the lettered diagram, which was crucial in the transmission of the knowledge system of Euclidean geometry.[63] Still, this knowledge depended on shared practical knowledge regarding the ruler and compass construction. Later, we find diagrams of different sorts playing an increasingly important role in the representation and transmission of technological and architectural knowledge. Even machines can be designed as external representations of mental models, with the Antikythera mechanism (second century BCE), which was an elaborate mechanical computer designed to calculate the position of celestial bodies, being the most celebrated and spectacular example from antiquity.[64]

3.13 A Typology of Transmission Processes

After having considered the typology of different forms of knowledge and that of its external representations, we now turn to the characteristics of transmission processes. Knowledge transmission processes vary along three basic dimensions. The first is mediation: is the knowledge transmitted through direct personal contact or through external representations? In immediate transfer, the principal external representations are ephemeral—speech and action. The two main processes of immediate transfer are imitation and instruction. In mediated transfer the external representations may or may not be explicitly designed to represent knowledge. Stimulus transfer is a paradigmatic case of transmission via a representation not explicitly designed to represent knowledge, while transmission by writing is a paradigmatic instance of the other case. The second dimension is directness: for the transmission process considered, was the knowledge transmitted directly from end to end, or were there relays? The third dimension is intentionality: is the knowledge transmitted intentionally or accidentally?

Transmission processes must always be studied within the interaction sphere of the transmitting and receiving actors constituting an epistemic network. A historical background condition is the varying mobility of actors, be they individuals, social groups, or societies. Receivers of knowledge should not be conceived of as passive, since they may resist the transmitted knowledge or appropriate and adapt it to their own knowledge in an equilibration process.[65] The transmission of individual items of knowledge or relatively specific knowledge complexes occurs much more frequently than the transmission of large systems of knowledge. In the words of Cyril Stanley Smith, “a human culture, existing at the apex of a long chain of

[62] See (Damerow 2012).
[63] See (Netz 1999).
[64] See (de Price 1974; Freeth et al. 2006; Freeth 2009).
[65] See chapter 14.

historical selectivity, cannot easily incorporate large chunks of another" (Smith 1977, 84). Knowledge may also be so embedded in culturally specific institutions that it is difficult to extract and hence difficult to transmit. Or the processes of extraction may so radically change the structural relations of the knowledge to other items of knowledge that the knowledge extracted is transformed into new knowledge. Another type of embeddedness is found in complex codes (semiotic systems) that depend on meta codes (that is, rules from outside the representational system).[66] Transmission processes are not simply either successful or not, but always involve selection and transformation; thus writing becomes a selective force in the transmission of knowledge, as what is not written is usually lost.[67]

In prehistorical knowledge transfer, both immediate and mediated processes must have played a role. Long-distance transfer was almost certainly by relay. Stimulus diffusion is an instance of a mediated but accidental process. Even when direct transfer took place, however, we cannot overlook the significance of the technological artifacts themselves in knowledge transmission. The importance of technological artifacts continues into Babylonian and Greek science and continues to play (an often ignored) role even in present-day science.[68] In the case of oral transmission, both instruction and imitation play a role; and we can infer from present-day cultures where bodies of knowledge are transmitted orally that bards first served as apprentices to a master. The transmission of orally encapsulated knowledge through time and space is an instance of transmission by relay.

Although writing was not initially a means for the transmission of knowledge, it began to assume that role quite early and became the dominant means for the mediated transmission of knowledge from the second millennium BCE on. Since some writing materials, such as papyrus, were of limited durability, texts needed to be copied, another instance of relay transmission. The transmission of knowledge via writing required the transmission of the knowledge of how to write, typically by instruction. As writing spread to different cultures, which spoke different languages and/ or had different media of writing available, the technology was adapted to local conditions. We see this adaptation, for example, in the spread of cuneiform to Elam or Anatolia (to write Hittite), or the spread of the Phoenician alphabet to Greece. Such a process of transmission followed by adaptation to local conditions can also be seen in prehistoric metallurgy and ceramic technology, which was transmitted, but then employed for the making of products markedly different from those made elsewhere.[69] In the ancient world, scientific knowledge spreads intermittently, since it can lie dormant in writing, with a Greek mathematician, for instance, picking up a problem from a mathematician who lived decades or even centuries earlier.

[66]See chapter 21.
[67]See the extensive discussions of the concept of transformation in (Renn and Damerow 2007; Damerow and Renn 2010; Böhme et al. 2011).
[68]See, for example, the discussion in (Daston 2000).
[69]See chapter 4.

3.14 From the Early History of Knowledge to the Origins of Science

Let us briefly summarize the early history of knowledge and its long-term consequences. Sociocultural evolution inherently involves knowledge that is efficacious, either with respect to the physical world or with respect to the social world. Once external representations of knowledge that are intended to represent knowledge are exchanged, there can be said to be a knowledge economy. At first this knowledge economy was almost completely tied to the underlying economy of labor. For example, literacy was closely correlated with socioeconomic status, and in Babylonia astronomical knowledge was pursued for agricultural and legitimatory ends, so that the pursuit of astronomical knowledge was ultimately motivated by economic concerns.

But when institutions devoted to the production and exchange of knowledge emerged that were emancipated from other labor, the knowledge economy became in principle decoupled from the economy of labor, although there some degree of entanglement always remained. The emergence of institutions centered around the production and exchange of knowledge made first exploratory knowledge and then science possible, as knowledge could now be pursued for the sake of means rather than ends. In the ancient world, we see several incipient beginnings of science. But epistemic evolution had not yet begun, because there was a severely limited number of hubs of knowledge production, and the network linking these was both fragile and inefficient. Only with the rise of science in the early modern period, economic and social conditions allowed for a robust and scale-free network sustaining the knowledge economy. At this point, the labor economy became increasingly dependent on the knowledge economy, and eventually, change in human society became driven by epistemic evolution, giving rise to socioepistemic evolution although the layers of sociocultural and biological evolution persisted.

Human sedentariness, together with the technologies that sedentariness enabled (e.g., metallurgy, ceramics) was a contingent historical development. The economic structure of sedentary societies, however, generated the capability for and the impulse to expansion, exploration, contact and borrowing (accumulation of knowledge).[70] Thus when sedentariness emerged, it began quickly to spread, transporting a package of knowledge as well. Sedentariness spread both from the West and East, effectively allowing for the transmission of knowledge throughout the whole of Eurasia, with transmission impeded in certain places by geographic obstacles.

The centrally administered state arose in Mesopotamia together with the technologies of writing and arithmetic. These two technologies sprang from the same origin, that is, from large-scale administrative experiences, but soon grew widely divergent.[71] These technologies had two reflective consequences: the formation of

[70] For the spread of knowledge before sedentariness, see (Sahlins 1972). For discussions of the neolithization process, see (Cauvin and Watkins 2000; Hodder et al. 2001; Kozlowski and Aurenche 2005).

[71] See chapter 6.

arithmetic concepts and the formation of metalinguistic awareness. Once writing came to represent language, it caused reflection upon language, and this reflection in turn altered patterns of use in language, thus restructuring language. Internalization of the technology of writing created a mental model of writing that could be applied to diverse contexts. Thus the Babylonians saw “heavenly writing” in the skies and priests “read” organs in extispicy. Later, the model allows authors from Augustine through the early modern period to consider a “book of nature,” and today we apply the model in contexts ranging from the transcription of DNA to the “read” and “write” operations of computer I/O.

Although writing is probably not a necessary condition for scientific knowledge, in the Greek world science developed through the reflective potentials offered by writing and transmitted geographically and historically by writing. The history of knowledge is a layered history, in which more recent knowledge is built upon successive layers of older knowledge. Thus Greek science rested on writing, a technology that had once served narrow ends of civic administration. The earliest writing, in turn, presupposed knowledge of even earlier symbol systems, as well as the practical knowledge of creating materials suitable for writing on and with. Thus “weight” is a second-order concept that emerges from reflecting on the knowledge gained by the operation of weighing objects with a balance, a technology developed toward the end of the second millennium in Babylonia and Egypt, that exploited metallurgic knowledge many millennia older.[72] Our discussion began with the story of simple craft technologies, a story that has often been told with no reference at all to knowledge. But these ancient craft technologies provided mental models that aided the Greeks in the creation of their science. Thus in cosmology, Anaximander likens the cosmic rings to wheels, and in mechanics the balance is employed as a mental model that explains all machines that allow small forces to achieve large effects. In this layered history, we see quite concretely the path from technology transfer to the origins of science.

References

Adcock, G. J., E. S. Dennis, E. Simon, G. A. Huttley, L. S. Jermiin, W. J. Peacock, and A. Thorne (2001). Mitochondrial DNA Sequences in Ancient Australians: Implications for Modern Human Origins. *Proceedings of the National Academy of Sciences of the United States of America 98*(2), 537–542.

Alster, B. (2005). *Wisdom of Ancient Sumer.* Bethesda, MD: CDL Press.

Andrews, P. and C. Stringer (1989). *Human Evolution: An Illustrated Guide.* New York: Press Syndicate of the University of Cambridge.

Baines, J., J. Bennet, and S. Houston (Eds.) (2008). *The Disappearance of Writing Systems: Perspectives on Literacy and Communication.* London: Equinox.

[72] See (Damerow et al. 2002; Renn and Damerow 2012).

Bauer, J. (1998). Der Vorsargonische Abschitt der Mesopotamischen Geschichte. In P. Attinger and M. Wäfler (Eds.), *Mesopotamien: Späturuk-Zeit und Frühdynastische Zeit*, Volume 160/1 of *Annäherungen. Orbis Biblicus et Orientalis*, pp. 431–585. Göttingen: Vandenhoeck & Ruprecht.

Benveniste, E. (1945). La Doctrine Médicale des Indo-Européens. *Revue de l'histoire des religions* (13), 5–12.

Benveniste, E. (1969). *Le vocabulaire des institutions indo-européennes.* Paris: Èdition Minuit.

Biggs, R. D. (1966). The Abū Ṣalābīkh Tablets. A Preliminary Survey. *Journal of Cuneiform Studies 20*(2), 73–88.

Biggs, R. D. and J. Postgate (1975). Inscriptions from Tell Abu Salabikh. *Iraq 40*(2), 101–118.

Böhme, H., L. Bergemann, M. Dönike, A. Schirrmeister, G. Toepfer, M. Walter, and J. Weitbrecht (Eds.) (2011). *Transformation. Ein Konzept zur Erforschung kulturellen Wandels.* Munich: Wilhelm Fink.

Cagni, L. (Ed.) (1981). *La Lingua di Ebla: atti del convegno internazionale.* Naples: Istituto Universitario Orientale.

Cardona, G., H. M. Hoenigswald, and A. Senn (Eds.) (1970). *Indo-European and Indo-Europeans: Papers Presented at the Third Indo-European Conference at the University of Pennsylvania.* Pennsylvania: University of Pennsylvania Press.

Cauvin, J. and T. Watkins (2000). *The Birth of the Gods and the Origins of Agriculture.* Cambridge: Cambridge University Press.

Charpin, D., D. O. Edzard, and M. Stol (2004). *Mesopotamia: The Old Assyrian*, Volume 160/4 of *Annäherungen. Orbis Biblicus et Orientalis.* Göttingen: Vandenhoeck & Ruprecht.

Cleuziou, S. and M. Tosi (1994). Black Boats of Magan: Some Thoughts on Bronze Age Water Transport in Oman and Beyond From the Impressed Bitumen Slabs of Ra's al-Junayz. In A. Parpola (Ed.), *South Asian Archaeology*, Volume 3, pp. 745–761. Helsinki: Suomalainen Tiedeakatemia.

Collins, J. and R. Blot (2003). *Literacy and Literacies: Texts, Power and Identity*, Volume 22 of *Studies in the Social and Cultural Foundations of Language.* Cambridge: Cambridge University Press.

Collison, R. (1964). The Beginnings. In *Encyclopaedias: Their History Throughout the Ages*, pp. 21–43. New York: Hafner Publishing Company.

Damerow, P. (1996). *Abstraction and Representation: Essays on the Cultural Revolution of Thinking*, Volume 175 of *Boston Studies in the Philosophy of Science*. Dordrecht: Kluwer.

Damerow, P. (1998). Prehistory and Cognitive Development. In J. Langer and M. Killen (Eds.), *Piaget, Evolution, and Development*, pp. 247–269. Mahwah, NJ: Erlbaum.

Damerow, P. (2001). Kannten die Babylonier den Satz des Pythagoras? Epistemologische Anmerkungen zur Natur der Babylonischen Mathematik. In J. Høyrup and P. Damerow (Eds.), *Changing Views of Ancient Near Eastern Mathematics*, pp. 219–310. Berlin: Reimer.

Damerow, P. (2010). Book Review: From Numerate Apprenticeship to Divine Quantification. *Notices of the American Mathematical Society 57*(3), 380–384.

Damerow, P. (2012). The Impact of Notation Systems: From the Practical Knowledge of Surveyors to Babylonian Geometry. In M. Schemmel (Ed.), *Spatial Thinking and External Representation: Towards a Historical Epistemology of Space*, Max Planck Research Library for the History and Development of Knowledge, pp. 376. Berlin: Edition Open Access.

Damerow, P. and W. Lefèvre (Eds.) (1981). *Rechenstein, Experiment, Sprache: historische Fallstudien zur Entstehung der exakten Wissenschaften.* Stuttgart: Klett-Cotta.

Damerow, P. and J. Renn (2010). The Transformation of Ancient Mechanics into a Mechanistic World View. In G. Toepfer and H. Böhme (Eds.), *Transformationen antiker Wissenschaften*, pp. 243–267. Berlin: De Gruyter.

Damerow, P., J. Renn, S. Rieger, and P. Weinig (2002). Mechanical Knowledge and Pompeian Balances. In J. Renn and G. Castagnetti (Eds.), *Homo Faber: Studies on Nature, Technology, and Science at the Time of Pompeii*, Volume 6 of *Studi della Soprintendenza Archeologica di Pompei*, pp. 93–108. Rome: L'Erma di Bretschneider.

Daston, L. (Ed.) (2000). *Biographies of Scientific Objects.* Chicago: University of Chicago Press.

de Price, D. S. J. (1974). Gears from the Greeks: The Antikythera Mechanism – A Calendar Computer from ca. 80 BC. *Transactions of the American Philosophical Society 46*(7), 1–70.

Denham, T. P., S. G. Haberle, C. Lentfer, R. Fullagar, J. Field, M. Therin, N. Porch, and B. Winsborough (2003). Origins of Agriculture at Kuk Swamp in the Highlands of New Guinea. *Science 301*(5630), 189–193.

Diamond, J. M. (1998). *Guns, Germs, and Steel: The Fates of Human Societies.* New York: Norton.

Englund, R. K. (1998). Texts from the Late Uruk Period. In P. Attinger and M. Wäfler (Eds.), *Mesopotamien: Späturuk-Zeit und Frühdynastische Zeit*, Volume 160/1 of *Annäherungen. Orbis Biblicus et Orientalis*, pp. 15–233. Göttingen: Vandenhoeck & Ruprecht.

Freeth, T. (2009). Decoding an Ancient Computer. *Scientific American 301*(6), 76–83.

Freeth, T., Y. Bitsakis, X. Moussas, J. H. Seiradakis, A. Tselikas, H. Mangou, M. Zafeiropoulou, R. Hadland, D. Bate, A. Ramsey, M. Allen, A. Crawley, P. Hockley, T. Malzbender, D. Gelb, W. Ambrisco, and M. G. Edmunds (2006). Decoding the Ancient Greek Astronomical Calculator Known as the Antikythera Mechanism. *Nature 444*(7119), 587–591.

Gelb, I. J. (1952). *A Study of Writing: The Foundations of Grammatology.* Chicago: University of Chicago Press.

Gelb, I. J. (1963). *A Study of Writing* (2. ed.). Chicago: University of Chicago Press.

Goody, J. (1986). *The Logic of Writing and the Organization of Society.* Studies in Literacy, Family, Culture and the State. Cambridge: Cambridge University Press.

Goody, J. and I. Watt (1963). The Consequences of Literacy. *Comparative Studies in Society and History 5*(3), 304–345.

Grün, R., C. Stringer, F. McDermott, R. Nathan, N. Porat, S. Robertson, L. Taylor, G. Mortimer, S. Eggins, and M. McCulloch (2005). U-Series and ESR Analyses of Bones and Teeth Relating to the Human Burials from Skhul. *Journal of Human Evolution 49*, 316–344.

Halverson, J. (1992). Goody and the Implosion of the Literacy Thesis. *Man 27*(2), 301–317.

Haudry, J. (1981). *Les Indo-Européens.* Paris: Presses Universitaires de France.

Hodder, I., G. O. Rollefson, O. Bar-Yosef, and T. Watkins (2001). Review Feature: *The Birth of the Gods and the Origins of Agriculture* by Jacques Cauvin, translated by Trevor Watkins (New Studies in Archaeology). *Cambridge Archaeological Journal 11*(1), 105–121.

Hole, F. (1987). *The Archaeology of Western Iran: Settlement and Society from Prehistory to the Islamic Conquest.* Washington, D.C: Smithsonian Institution Press.

Houston, S. D. (Ed.) (2004). *The First Writing: Script Invention as History and Process*. Cambridge: Cambridge University Press.

Hyman, M. D. (2006). Of Glyphs and Glottography. *Language and Communication 26*(3–4), 231–249.

Kharakwal, J. S., A. Yano, Y. Yasuda, V. S. Shinde, and T. Osada (2004). Cord Impressed Ware and Rice Cultivation in South Asia, China and Japan: Possibilities of Inter-links. *Quaternary International*, 105–115.

Kozlowski, S. and O. Aurenche (2005). *Territories, Boundaries and Cultures in the Neolithic Near East*. Oxford: Archaeopress.

Krebernik, M. (1984). *Die Beschwörungen aus Fara und Ebla: Untersuchungen zur ältesten keilschriftlichen Beschwörungsliteratur*, Volume 2 of *Texte und Studien zur Orientalistik*. Hildesheim: Olms.

Krebernik, M. (1998). Die Texte aus Fara und Tell Abu Salabikh. In P. Attinger and M. Wäfler (Eds.), *Mesopotamien: Späturuk-Zeit und Frühdynastische Zeit*, Volume 160/1 of *Annäherungen. Orbis Biblicus et Orientalis*, pp. 237–427. Göttingen: Vandenhoeck & Ruprecht.

Krebernik, M. (2007a). Buchstabennamen, Lautwerte und Alphabetgeschichte. In R. Rollinger, A. Luther, and J. Wiesehöfer (Eds.), *Getrennte Wege? Kommunikation, Raum und Wahrnehmung in der alten Welt*, pp. 108–175. Frankfurt am Main: Verlag Antike.

Krebernik, M. (2007b). Zur Entwicklung des Sprachbewusstseins im Alten Orient. In C. Wilcke (Ed.), *Das geistige Erfassen der Welt im Alten Orient*, pp. 39–62. Wiesbaden: Harrasowitz.

Lambert, W. G. (1957). Ancestors, Authors and Canonicity. *Journal of Cuneiform Studies 11*(1), 1–14.

Larick, R. and R. L. Ciochon (1996). The African Emergence and Early Asian Dispersals of the Genus Homo. *American Scientist* (84), 538–551.

Lawergren, B. (1994). Buddha as a Musician: An Illustration of a Jataka Story. *Artibus Asiae 54*(3–4), 226–240.

Lejju, B. J., P. Robertshaw, and D. Taylor (2006). Africa's Earliest Bananas? *Journal of Archaeological Science 33*(1), 102–113.

Liu, L., A.-G. Lee, L. Jiang, and J. Zhang (2007). Evidence for the Early Beginning (c. 9000 cal. BP) of Rice Domestication in China: A Response. *The Holocene* (17), 1059–1068.

Lloyd, G. E. R. (1996). *Adversaries and Authorities: Investigations into Ancient Greek and Chinese Science*. Cambridge: Cambridge University Press.

Lloyd, G. E. R. (2002). *The Ambitions of Curiosity: Understanding the World in Ancient Greece and China*. Cambridge: Cambridge University Press.

Malkin, I. (2011). *A Small Greek World: Networks in the Ancient Mediterranean*. Oxford: Oxford University Press.

Mallory, J. and D. Adams (2006). *The Oxford Introduction to Proto-Indo-European and the Proto-Indo-European World*. Oxford: Oxford University Press.

McDougall, I., F. H. Brown, and J. G. Fleagle (2005). Stratigraphic Placement and Age of Modern Humans from Kibish, Ethiopia. *Nature 433*(7027), 733–736.

McDougall, I., F. H. Brown, and J. G. Fleagle (2008). Sapropels and the Age of Hominins Omo I and II, Kibish, Ethiopia. *Journal of Human Evolution 55*(3), 409–420.

Meyer, C., J. M. Todd, and C. W. Beck (1991). From Zanzibar to Zagros: A Copal Pendant from Eshnunna. *Journal of Near Eastern Studies 50*(4), 289–298.

Needham, J. (1988). *Science and Civilization in China* (Reprint ed.), Volume 1–8 of *Science and Civilization in China*. Cambridge: Cambridge University Press.

Netz, R. (1999). *The Shaping of Deduction in Greek Mathematics: A Study in Cognitive History*. Cambridge: Cambridge University Press.

Neugebauer, O. (1957). *The Exact Sciences in Antiquity*. New York: Dover.

Nissen, H. J., P. Damerow, and R. K. Englund (1993). *Archaic Bookkeeping: Early Writing and Techniques of Economic Administration in the Ancient Near East*. Chicago: Chicago University Press.

Ong, W. J. (1986). Writing Is a Technology that Restructures Thought. In G. Baumann (Ed.), *The Written Word: Literacy in Transition*, pp. 23–50. Oxford: Clarendon Press.

Pereira, L., M. Richards, A. Goios, A. Alonso, C. Albarrán, O. Garcia, D. Behar, M. Gölge, J. Hatina, L. Al-Gazali, D. Bradley, V. Macaulay, and A. Amorim (2005). High-Resolution mtDNA Evidence for the Late-Glacial Resettlement of Europe from an Iberian Refugium. *Genome Research* (15), 19–24.

Potts, D. T. (1995). Watercraft of the Lower Sea. In U. Finkbeiner (Ed.), *Beiträge zur Kulturgeschichte Vorderasiens: Festschrift für Rainer M. Boehmer*, pp. 559–571. Mainz: Von Zabern.

Potts, D. T. (2004). Camel Hybridization and the Role of *Camelus bactrianus* in the Ancient Near East. *Journal of the Economic and Social History of the Orient 47*(2), 143–165.

Ptak, R. (2007). *Die maritime Seidenstraße: Küstenräume, Seefahrt und Handel in vorkolonialer Zeit.* Munich: Beck.

Quintana-Murci, L., O. Semino, H.-J. Bandelt, G. Passarino, K. McElreavey, and A. Santachiara-Benerecetti (1999). Genetic Evidence of an Early Exit of Homo Sapiens Sapiens from Africa through Eastern Africa. *Nature Genetics* (23), 437–441.

Ray, H. P. R. and D. T. Potts (Eds.) (2007). *Memory as History: The Legacy of Alexander in Asia.* New Delhi: Aryan Books International.

Renfrew, C. (2009). *Prehistory: The Making of the Human Mind.* New York: Modern Library.

Renfrew, C. and E. B. Zubrow (Eds.) (1994). *The Ancient Mind: Elements of Cognitive Archaeology.* Cambridge: Cambridge University Press.

Renn, J. and P. Damerow (2007). Mentale Modelle als kognitive Instrumente der Transformation von technischem Wissen. In H. Böhme, C. Rapp, and W. Rösler (Eds.), *Übersetzungen und Transformationen*, Volume 1 of *Transformationen der Antike*, pp. 311–331. Berlin: De Gruyter.

Renn, J. and P. Damerow (2012). *The Equilibrium Controversy. Guidobaldo del Monte's Critical Notes on the Mechanics of Jordanus and Benedetti and their Historical and Conceptual Background.* Max Planck Research Library for the History and Development of Knowledge, Sources 2. Berlin: Edition Open Access.

Renn, J. and M. Schemmel (2006). Mechanics in the Mohist Canon and Its European Counterpart. In H. U. Vogel, C. Moll-Murata, and G. Xuan (Eds.), *Zhongguo ke ji dian ji yan jiu: di san jie Zhongguo ke ji dian ji guo ji hui yi lun wen ji, 2003.3.31–4.3, Deguo Tubingen*, pp. 24–31. Zhengzhou: Elephant Press (Da xiang chu ban she).

Robson, E. (2008). *Mathematics in Ancient Iraq: A Social History.* Princeton, NJ: Princeton University Press.

Rubin, D. C. (1995). *Memory in Oral Traditions: The Cognitive Psychology of Epic, Ballads, and Counting-Out Rhymes.* New York: Oxford University Press.

Russo, L. (2004). *The Forgotten Revolution. How Science Was Born in 300 BC and Why It Had to Be Reborn.* Heidelberg: Springer.

Sahlins, M. (1972). The Original Affluent Society. In M. Sahlins (Ed.), *Stone Age Economics*, pp. 1–41. Hawthrone: de Gruyter.

Sallaberger, W. (1999). Ur III-Zeit. In P. Attinger and M. Wäfler (Eds.), *Mesopotamien: Akkade-Zeit und Ur-III Zeit*, Volume 160/3 of *Annäherungen. Orbis Biblicus et Orientalis*, pp. 121–390. Göttingen: Vandenhoeck & Ruprecht.

Sasson, J. M. (Ed.) (1995). *Civilizations of the Ancient Near East.* New York: Charles Scribner's Sons.

Scharf, P. M. and M. D. Hyman (2012). *Linguistic Issues in Encoding Sanskrit.* Delhi: Motilal Banarsidass Publishers.

Schwarcz, H. P., R. Grün, B. Vandermeersch, O. Bar-Yosef, H. Valladas, and E. Tchernov (1988). ESR Dates for the Hominid Burial Site of Qafzeh in Israel. *Journal of Human Evolution 17*(8), 733–737.

Smith, C. S. (1977). Review of Bernard, N. and Sato, T., Metallurgical Remains of Ancient China; and Ho, P.-T., The Cradle of the East: An Enquiry into the Indigenous Origins of Techniques and Ideas of Neolithic and Early Historic China, 5000–1000 B.C. *Technology and Culture 18*(1), 80–86.

Soficaru, A., A. Dobos, and E. Trinkaus (2006). Early Modern Humans from the Pestera Muierii, Baia de Fier, Romania. *Proceedings of the National Academy of Sciences of the United States of America 103*(46), 17196–17201.

Soficaru, A., C. Petrea, A. Dobos, and E. Trinkaus (2007). The Human Cranium from the Pestera Cioclovina Uscata, Romania: Context, Age, Taphonomy, Morphology, and Paleopathology. *Current Anthropology 48*(4), 611–619.

Staal, F. (1999). Greek and Vedic Geometry. *Journal of Indian Philosophy 27*(1), 105–127.

Stauder, A. (2010). The Earliest Egyptian Writing. In C. Woods (Ed.), *Visible Language: Inventions of Writing in the Ancient Middle East and Beyond.* Chicago: Oriental Institute Press.

Szabó, A. (1978). *The Beginnings of Greek Mathematics.* Dordrecht: D. Reidel.

Templeton, A. (2002). Out of Africa Again and Again. *Nature 416*(6876), 45–51.

Thorndike, L. (1923). *A History of Magic and Experimental Science. Part 1. During the First Thirteen Centuries of Our Era.* New York: MacMillan.

Uerpmann, H.-P. and M. Uerpmann (2002). The Appearance of the Domestic Camel in SE-Arabia. *Journal of Oman Studies* (12), 235–260.

Vasil'ev, S., Y. Kuzmin, L. Orlova, and V. Dementiev (2002). Radiocarbon-based Chronology of the Paleolithic in Siberia and its Relevance to the Peopling of the New World. *Radiocarbon* (44), 503–530.

Veenhof, K. R. and J. Eidem (2008). *Mesopotamia: The Old Assyrian*, Volume 160/5 of *Annäherungen. Orbis Biblicus et Orientalis*. Göttingen: Vandenhoeck & Ruprecht.

Watkins, C. (1995). *How to Kill a Dragon: Aspects of Indo-European Poetics*. New York: Oxford University Press.

Westenholz, A. (1999). The Old Akkadian Period: History and Culture. In P. Attinger and M. Wäfler (Eds.), *Mesopotamien: Akkade-Zeit und Ur-III Zeit*, Volume 160/3 of *Annäherungen. Orbis Biblicus et Orientalis*, pp. 17–117. Göttingen: Vandenhoeck & Ruprecht.

Woodard, R. D. (1997). *Greek Writing from Knossos to Homer: A Linguistic Interpretation of the Origin of the Greek Alphabet and the Continuity of Ancient Greek Literacy*. Oxford: Oxford University Press.

Woods, C. (Ed.) (2010). *Visible Language: Inventions of Writing in the Ancient Middle East and Beyond*. Chicago: Oriental Institute Press.