Chapter 5
Prehistoric Stone Tools and their Epistemic Complexity

Manjari Chakrabarty

Abstract In his 1997 paper "Technology and Complexity" Dasgupta draws a distinction between *systematic* and *epistemic complexity*. Entities are called *systematically complex* when they are composed of a large number of parts that interact in complicated ways. This means that even if one knows the properties of the parts one may not be able to infer the behaviour of the system as a whole. In contrast, epistemic complexity refers to the knowledge that is used in, or generated by the making of an artefact and is embodied in it. Interestingly, a high level of systematic complexity does not entail a high level of epistematic complexity and vice versa. Prehistoric stone tools, for example, display a unique combination of systematic simplicity with epistemic complexity. In order to attract the attention of philosophers of technology and engineering to the domain of prehistoric technology or what is called "First Technology", the present chapter aims to examine the epistemic complexity of, (that is to say the amount, variety and kind of knowledge embodied in) ancient Oldowan stone tools. The aim is addressed by critically reviewing and extending Karl Popper's unconventional objective approach to epistemology and by drawing upon recent experimental-archaeological research on Oldowan stone tool production.

Keywords Stone tools · Epistemic complexity · Operational principles · Objective knowledge

M. Chakrabarty (✉)
Visva-Bharati (Central University), Santiniketan, West Bengal, India
e-mail: manjari.chakraborty@visva-bharati.ac.in

Z. Pirtle et al. (eds.), *Engineering and Philosophy*, Philosophy of Engineering and Technology 37, https://doi.org/10.1007/978-3-030-70099-7_5

5.1 Introduction

In his 1997 paper "Technology and Complexity" Dasgupta draws a distinction between *systematic* and *epistemic complexity*. Following Herbert Simon (1962), Dasgupta calls entities *systematically complex* when they are composed of a large number of parts that interact in complicated ways. This means that even if one knows the properties of the parts one may not be able to infer the behaviour of the system as a whole. Epistemic complexity, on the other hand, consists of the knowledge that is used in, and is generated by the making or production of an artefact. In Dasgupta's (1997:116) words, epistemic complexity refers to the richness (i.e., the amount, variety, and newness) of the knowledge embedded in an artefact. What's more, epistemic complexity appears not simply because of the volume of knowledge but by the combination of old and new knowledge in unanticipated ways (Dasgupta 1997: 118).

While both natural and artificial things[1] are manifestly more or less complex in the systemic sense, epistemic complexity is typically characteristic of artificial things or artefacts that are produced or consciously conceived in response to some practical need, want or desire (Dasgupta 1997: 114). Important is to note, systematic and epistemic complexities are not necessarily coupled (Dasgupta 1997: 130), that is, a high level of systematic complexity does not entail a high level of epistemic complexity and vice versa. Artefacts can either be (i) systemically complex but epistemically (relatively) simple, or (ii) they can be systemically complex and, consequently, epistemically complex, or (iii) they can be systemically quite simple but epistemically complex (Dasgupta 1997: 118). Artefacts that have been designed and manufactured several times in the past according to some well-established styles (e.g., aircraft engines made prior to the advent of turbojet) belong to the first group (Dasgupta 1997: 118–120). For, such artefacts may be systematically complex, but their design-process may not produce any significant new knowledge. As an example of the second group of artefacts illustrating how a high level of systematic complexity causes a high level of epistemic complexity Dasgupta (1997: 122–125) cites *Multics* – a specific computer operating system developed in the 1960s. Examples of artefacts belonging to the third group has been gleaned by him (Dasgupta 1997: 125–128) from the prehistorical-archaeological record of technological practices.

Prehistoric stone tools, Dasgupta (1997: 125–128) cogently argues, display a unique coupling of systematic simplicity with epistemic complexity. One could not easily think of any systematically simpler objects than ancient stone tools which are hardly distinguishable from natural pebbles by any lay person. These stone tools are not composed of any separable parts either. Evidently, per Simon's (1962) criterion, early stone tools are systematically simple. The manufacturing and use of

[1] The terms 'artificial things,' 'artefacts' and 'technical artefacts' used interchangeably in this chapter refer to any product of human (or hominin) activities, conceived, manufactured or modified in response to some need, want or desire to produce an intended result.

such primitive stone tools, however, generated quite significant and new knowledge. Therefore, despite being systematically unsophisticated these ancient stone tools are epistemically quite rich and complex. The proposed study aims to contribute to the philosophy of technology by reflecting on the nature of knowledge incorporated in these prehistoric stone tools. Dasgupta's (1997) first-ever analysis of these systematically simple stone tools as "embodiments of considerable original knowledge" (Dasgupta 1997: 125) inspires the following discussion for two reasons. First, it throws fresh light on an important but neglected task of philosophy of technology, namely, scrutinizing the nature of knowledge embodied in technical artefacts; and second, it provides the much-needed impetus to philosophers engaged with technology and engineering to explore the domain of prehistoric stone technology or what is called 'First Technology' (Toth 1987). While the former reason has the controversial implication that knowledge can take on material, artefactual forms, the latter indicates that issues entangled with the manufacturing and use of stone tools are also important for contemporary philosophers of technology and engineering. The present chapter, divided into three main sections, addresses both these issues.

The first section is largely concerned with stage-setting for arguments to come. It consists of a brief overview of Karl Popper's (1972) analysis of knowledge in the objective sense and seeks to explain why employing the Popperian approach to objective knowledge is indispensable for the present inquiry. The second section engages the metaphysical and epistemological speculations of three philosophers, namely, Popper's (1972) theory of objective knowledge (intertwined with his three-world metaphysical hypothesis), Baird's (2004) theory of 'thing knowledge' or material epistemology and Dasgupta's (1996) account of technological knowledge in order to address the issue of how materially constituted things or artefacts (e.g., tools, machines etc.) bear knowledge. The third section inquires into the stone tool production known as Oldowan (Leaky 1971) industrial complex and into the particular nature of knowledge embodied in these Oldowan tools by drawing upon recent experimental-archaeological research. The chapter ends with a few comments on the epistemic complexity of ancient Oldowan stone tools and on its implications for future investigations.

5.2 Section 1: Subjective vs Objective Perspectives of Knowledge

Knowledge, according to Popper (1972), can be understood or approached from two very different points of view. We can approach it from the personal or psychological or subjective side and consider knowledge as something in people's minds, say, a system of ideas or beliefs in the minds of human individuals. This may be called the subjective approach to knowledge, or the subjective approach in epistemology. However, we can also approach knowledge from the public, or impersonal or objective side and consider it as a system of statements, or propositions, or theories, i.e., a system of objective or non-psychological entities presented and made available in, say, a scientific publication or more generally speaking, stored in books and libraries. This may be called the objective approach to knowledge or the objective approach in epistemology.

It goes without saying that ideas or beliefs are conceived in human minds. Consequently, all (human) knowledge, which generally begins as a belief or an idea in the mind of some person, consists primarily of mental or psychological states. This, however, does not suggest that all knowledge is subjective or 'organismic knowledge', i.e., *merely* a variety of beliefs or mental states of the knowing subject (Popper 1972: 73). The linguistic formulations of our ideas or beliefs eventually deliver them into a 'wider and hostile world' (Miller 1995: 11) and the knowledge stored in a book, for example, is not identical with the knowledge in the mind of any human reader (Popper 1972).

The classical philosophical theory of knowledge has almost universally employed the subjective approach and has defined knowledge as a special kind of belief (in our minds) – knowledge consists of those (true) beliefs which can be justified (Musgrave 1993). Therefore, to say "A knows X," per this subjective interpretation, means something like "A believes X", "X is true", and "A can justify her belief that X." To a large extent the history of the theory of knowledge appears to be the history of a great debate about whether one could know anything, in this sense of 'know' (Musgrave 1993).

Popper (1972) noticed that in this traditional epistemological account the term 'belief' ambiguously denotes both a particular mental *act* or *attitude*, and *that* which is believed (or thought), i.e., the *content* towards which the *act* or *attitude* of believing (or thinking) is directed. For, the distinction between *thought contents* (for e.g., statements or theories) and the various psychological attitudes or feelings or responses (which people may have towards these contents), i.e., *thought processes* has, more often than not, been ignored. Epistemological *acts*, such as the *act* of believing, or the *act* of thinking, possess very different properties and relationships from those possessed by their *contents*. The kinds of question we can properly ask about an epistemological *act* are very different from the kinds of question we can properly ask about its *content* (Popper 1972; Musgrave 1974). For example, one might ask of the *content* of some belief or thought whether it is true or self-consistent, or consistent with other contents of our beliefs, or whether it follows logically from another content of our belief or thought. It need hardly be said that personal or psychological considerations about the believer or thinker are not essential for answering the above questions. These questions, thus, are objective in the sense that in answering them we do not need to consider the facts about mental *acts* or *attitudes* which may or may not be adopted (by all or some persons) towards the *contents* involved.

Mental *acts* or *attitudes*, on the other hand, stand in factual, psychological relationships to each other. We might ask of an *act* of believing (or thinking) whether it is strong or weak, or what motivated it, or whether it was arrived at by taking arguments and evidence into account, or whether it was reckless and hasty. These questions are subjective in the sense that personal or psychological considerations about the believer or thinker are necessary to answer them (Popper 1972). Evidently, every epistemological act has both an objective and a subjective dimension and can be approached from either a subjective or an objective point of view. Though each of these approaches is a legitimate one, traditional epistemology has almost uncritically neglected this objective perspective on knowledge. In fact, the very possibility of an objective approach has seldom been seriously considered. This explains why Popper's name does not appear in most anthologies on epistemology. An unfortunate consequence of this traditional negligence is the absence of Popper from almost all historical-philosophical investigations into technological knowledge.

Approached from this Popperian objective viewpoint, knowledge may be construed as an abstract, evolutionary human construction that can be detached from its psychological origin, can be criticized and modified inter-subjectively, and that can improve 'by exosomatic (non-genetic) means' (Miller 2011: 3) active human adaptation to the world. A key feature of Popper's (1972) theory of objective knowledge is that it separates the private origins of knowledge from its public manifestations and emphasizes the depersonalized, objective character of those manifestations. To borrow an example from Popper (1979), the abstract, objective content (i.e., the same text, the same sequence of sentences, same syntactical properties) of a book – say, the American Constitution– that remains invariant through various editions, can be grasped, known, or criticized inter-subjectively for matters like logical consistency, compatibility etc. without taking the private origins of the content into consideration.

This distinction between the traditional subjective approach and the Popperian objective approach to knowledge, however, is not to be confused with the distinction often made by philosophers (particularly those engaged with technology and engineering) between propositional knowledge and non-propositional or tacit knowledge.[2] While the former is basically a distinction between two legitimate methodological approaches to knowledge, the latter is a distinction between two distinct kinds of knowledge.[3]

In order to examine the epistemically complex character of early stone tools (like prehistoric hand-axes and choppers) one must adopt the Popperian objective approach to knowledge. For, if knowledge is understood as essentially an affair of the human mind, a special kind of belief or some mental states, these ancient stone tools being epistemically complex entities would have to be interpreted as some early form of hominin beliefs or hominin mental or psychological acts. This construal of stone tools as some primitive and private hominin mental acts or processes seems untenable not only from the commonsensical standpoint but, more importantly, from the archaeological perspective. The prehistoric stone tools excavated

[2] For the distinction between explicit and tacit knowledge see. e.g., Vincenti (1984), and (Houkes 2009).

[3] We do not assume here that technological knowledge is simple know-how or non-propositional, practical knowledge. For more details on the heterogenous nature of technological knowledge see Dasgupta (1996).

and studied by the archaeologists cannot be some psychological or mental acts or states internal to hominin minds or brains (whatever else they might be).

In contrast to the subjective standpoint, if one interprets knowledge from the objective perspective a very different picture emerges. Approached from the (Popperian) objective point of view, knowledge may be considered as a system of non-psychological entities, such as the linguistically formulated content of our theories or conjectures or arguments that can be subjected to inter-subjective scrutiny and modification independent of the issues related to their genesis. If knowledge is understood in the above sense, then prehistoric choppers and hand axes, instead of being seen as some private mental acts (or processes) within ancient hominin minds or brains, may be described as tangible hominin constructions (much like the nests built by the birds or webs woven by the spiders) accessible for further investigation and modification by anyone interested (e.g., archaeologists or historians) independent of the psychological considerations of those ancient stone tool makers.

Thus, given the task of exploring the epistemic richness of early stone tools the Popperian perspective appears more advantageous than the more prevalent subjective approach to knowledge. The following sections probe this issue further as to why the knowledge entailed in (and generated by) the making, modifying, repairing and multiple use of these early stone tools cannot be reasonably reduced to some private and primitive kind of mental or psychological states of ancient hominin minds.[4] As traditional epistemology has almost uncritically ignored the very possibility of this Popperian objective approach, its prospects (and problems) have remained largely unexplored in historical-philosophical reflections on technological knowledge as well. What is worth noting, explaining knowledge from the objective side (as knowledge stored in books or libraries) doesn't ignore the significance of the subjective approach to knowledge (e.g., knowledge as *acts* of believing or thinking). Quite the contrary, Popper (1972:112–114) argued, an objective epistemology investigating the thought *products* or produced structures can help to throw an immense amount of light upon the acts of production or subjective thought *processes*.[5] For how else might the archaeologists develop insights into the more private domain of ancient hominin mental or psychological *acts* other than by closer scrutiny of the hominin (technological) products or artefacts such as the prehistoric stone tools?

Popper's argument for introducing a distinct realm or evolutionary level (which he calls World 3) for such objective products rests primarily on this critical and irreducible (but traditionally neglected) distinction between *acts* (or processes) of thought and *contents* (or products) of thought. Let me digress for a moment to present a very brief overview of Popper's three-world metaphysical hypothesis (Popper

[4] How technical ideas or thoughts can be expressed and conveyed through visual or pictorial forms has been brilliantly illustrated by Ferguson (1977). We will take up the issue in the next section.

[5] But the converse is not true because our thought *contents* or products are largely autonomous and not entirely reducible to our thought *processes*.

and Eccles 1977; Popper 1979). Reality, for Popper, is a tripartite phenomenon composed of an interacting triad of evolutionary levels (or worlds), namely, World 1, World 2 and World 3, emerged in the course of the evolution of the universe. Each of these distinct evolutionary levels (or worlds) is an irreducibly emergent[6] phenomenon and all three causally interact with one another.

World 1 is the physical world of matter and energy including stars, planetary systems, bodies, brains and so on– the world investigated by the physical scientists. Sometime prior to 3.5 billion years or some 4 billion years ago life in the form of unicellular, microorganisms (protobacteria) emerged from non-living matter. Life became complex progressively, as plants and animals of myriad forms and sizes evolved and interacted in fertile ecosystems. During the evolution of life on earth, some organisms, in a certain sense, became conscious and conscious organisms seemed better adapted to deal with the contingencies of their environments and to interact with their environments in ways that non-conscious organisms cannot. The emergence of consciousness marked a qualitative change in the structure of reality. A new realm of mental or psychological states and processes and subjective experiences (e.g., pangs, perceptions, thoughts) that Popper calls World 2 emerged. What makes World 2 as real as the physical world (World 1) is the fact that the former can interact with or influence the latter. The ability for causal interaction with hard physical bodies is, for Popper (Popper and Eccles 1977; Popper 1979), the core criterion for what is to count as real.

The next important development possibly were the emergence of self-consciousness and linguistic behaviour that, in turn, made the encoding of abstract contents of human thought possible. The products of human intellectual and physical activities belong to a different realm of reality which Popper calls World 3. Although the *thought contents* (constituting World 3) originate from *thought processes* (belonging to World 2), once formulated linguistically they become depersonalized, objective knowledge that can be grasped, known, deciphered and criticized by anyone concerned. Popper's theory clearly puts special emphasis on the use of language. We use language in order to describe or to argue but these descriptions or arguments can be considered independently of us (the users of the language) and our states of mind. For, the fundamental properties of descriptions (namely, truth and falsity) and those of arguments (namely, validity and invalidity) are objective properties which can be considered independently of the psychology of the describer or arguer. It is the use of language that adds a whole new dimension, to use Miller's (2011: 17) words, "the impersonal status" to human knowledge (considered as a subjective, organismic phenomenon) and emigrates it to a distinct level (called World 3) with its own problems and mysteries. This explains why Popper (1979) regarded linguistic entities like theories, propositions, the contents of scientific, mathematical or poetic ideas, problem-situations or critical arguments as the most fertile World 3 objects. Nevertheless, the Popperian World 3 also

[6] Things which are 'based on' certain processes but cannot be 'explained by' the theories of the underlying processes are to be understood as 'emergent' (Niemann 2014: 68).

includes materially constituted things like works of art and other ‘feats of engineering’ (Popper 1979: 2) such as, tools, books, aircrafts, computers or scientific instruments.

If artefacts like machines and instruments, being human constructions, belong to World 3, then prehistoric tools – arguably the earliest hominin creations – might also be considered as inmates of the same world. Archaeological data indicate that these ancient stone tools were not results of accidentally ‘bashing two rocks together’ (Leaky 1994: 38) but were flaked, examined, modified, reproduced, used and re-used by the early hominins. In order to belong to the third world of objective knowledge Popper’s minimal criterion is that “…a book should—in principle, or virtually—be capable of being grasped (or deciphered, or understood, or ‘known’) by somebody” (Popper 1972: 116). Just like a book can, in principle, be grasped, deciphered, understood, or known by somebody (and hence belong to World 3), these primitive stone tools, too, can, in principle, be deciphered, studied, and interpreted by anybody, say, by any modern-day researcher. Interestingly, when he was asked once how far back in the human prehistory can we trace the origin of the most primitive World 3 entities, Popper replied that the origin of a primitive World 3 may be detected in the ancient hominin tool behavior (Popper and Eccles 1977/1995: 450–453). If these prehistoric stone tools meet all conditions for Popper’s criterion for being a part of World 3 – the distinct realm of objective knowledge – then, it wouldn’t be too unreasonable to argue that they too possess epistemic contents in some significant sense. To investigate further into the epistemic complexity of these early stone tools a critical appraisal and extension of Popper’s theory of objective knowledge seems necessary and the next section undertakes the task.

5.3 Section 2: How Does Knowledge Take on Material Forms?

There are several reasons why artefacts like machines or instruments are considerd as epistemically complex entities or as bearers of knowledge. That knowledge in the objective sense may take on different forms has been suggested by scholars over the past four decades. Popper’s *Objective Knowledge* (1972) explicitly demonstrates the decisively non-psychological, objective character of (scientific and much of our common-sense) knowledge embodied in linguistically formulated statements or systems of statements. Subsequently, the nature and significance of non-verbal, visual knowledge incorporated in pictures and (technical) drawings of machines and other devices has been illustrated by Ferguson (1977). His (Ferguson 1977) research reveals how, beginning with the Renaissance, a vast body of characteristically visual knowledge was recoded, exchanged and conveyed exclusively by the pictures and drawings of machines or mechanical devices sans textual component.[7]

The next important publication is Dasgupta's (1996, 1997) meticulous study of the heterogenous nature of technological knowledge borne by a wide range of artefacts, such as a computer operating system known as *Multics*, the wrought-iron Britannia (tubular) bridge designed by Robert Stephenson and William Fairbairn in the 1840s, or the stone tools of the Lower Palaeolithic period. More recently, Baird's[8] (2004) work cites several intriguing historical cases and explains how scientific instruments and models themselves encapsulate knowledge in a manner different from theory. In sharp contrast to the conventional philosophical attitude of thinking about knowledge in exclusively propositional terms and of considering theories as the primary forms of knowledge Baird's (2004) material epistemology, popularly known as 'thing knowledge,' construes scientific instruments as bearers of knowledge themselves and not as mere aids in the generation and articulation of scientific knowledge as has been previously assumed (see e.g., Hacking 1983).

Notwithstanding these scholarly works on the epistemic character of artefacts, the following analysis is motivated by the recognition that an uncritical adoption of none of the theories mentioned above, namely, Popper's (1972) objective epistemology, Dasgupta's (1997) account of epistemic complexity and Baird's (2004) 'thing knowledge' seem to suffice for the present purposes.[9] All in all, I believe a deeper review of the existing literature is necessary for explaining how knowledge (in the Popperian objective sense) assumes material, artefactual forms. The present section will review this literature and attempt to develop a deeper synthesis.

Baird's (2004) material epistemology or 'thing-knowledge' quite convincingly highlights the critical need to go beyond the dominant theory-prone approaches of proposition-centred epistemology and it calls for adopting a new perspective towards the material products of science and technology. Though he is not the first one to question the suitability of the classical definition of knowledge (as justified-true-belief) in analyses of technological knowledge[10] he is a pioneer in developing an understanding of scientific instruments not as mere aids in the origination or articulation of knowledge but as bearers of epistemological content themselves. As a provocative challenge to the traditional proposition-based epistemology Baird's work surely deserves more scholarly attention than it has yet received. One insistent

[7] Italian engineer Ramelli's 1588 *Le Diverse et Artificiose Machine* or the German instrument maker Leupold's series of machine books entitled *Theatrum Machinarum* are examples of works that transmitted a huge amount of new technical ideas and information through mere illustrations of artefacts.

[8] To our surprise, Dasgupta (1996) has been inexplicably absent from Baird's (2004) book.

[9] Despite its unmatched significance Ferguson's (1977) study of how non-verbal thought recorded in technical drawings and images is not useful in a direct way for our investigation into the epistemic complexity of stone tools.

[10] Nordmann (2006), for example, argues that the knowledge of making, building, repairing artefacts or that of design cannot be properly examined by considering knowledge as a species of belief.

problem, however, is the extent to which we can accurately characterize the knowledge embodied in scientific instruments. As already noted, the subjective and objective views are two contrasting methodological approaches in epistemology. Knowledge can either be interpreted as some mental *acts* (or processes) – as psychological phenomena or as objective *contents* – as non-psychological, public phenomena. Preserving Popper's spirit but avoiding a strictly Popperian interpretation of objective knowledge Baird (2004: 128–133) highlights the close ties between objective knowledge and subjective beliefs or human consciousness and openly favours a "less extreme version of objective epistemology" leaving the very meaning of the phrase unexplained (Baird 2004: 128). The key Popperian insight Baird fails to note but could profitably use here is that understanding knowledge in the objective sense does not imply any denial of its subjective origins. Examination, evaluation or modification of objective knowledge, as Popper (1972) taught us, is possible independent of (though not ignoring) its subjective considerations or psychological origins. Despite being related in some significant sense with our mental or conscious acts or processes our scientific, mathematical or other theories, propositions, or critical arguments as objective knowledge, as World 3 entities are to a considerable extent autonomous[11] (because of their feedback effect on us) and hence irreducibly different from those private mental or conscious acts.

What is admirable in Baird's (2004) account is his bold suggestion for an extension Popper's theory of objective World 3 with a distinctly materialist basis. Stating baldly, Baird's (2004) argument is, as scientific models and instruments themselves contain and convey knowledge they should be regarded as exclusively World 3 entities like theories, hypotheses etc. Popper did include books, aircrafts, computers or other technical artefacts in World 3 but he regarded them as 'embodied' or 'physically realized' in World 1 physical objects (Popper 1979: 2–3). A part of World 3, he (Popper and Eccles 1977/1995: 41) argued elsewhere, has been 'materialized' or 'stored up' or 'encoded' in books or libraries or gramophone records or in people's memories, for example. While artefacts like books, paintings or sculptures possessing perceptible and measurable physical properties (such as weight, spatio-temporal location and so on) are embodied in World 1 objects, musical scores may exist encoded in gramophone records and entities like poems may exist either as memories (World 2 objects) or as memory traces encoded in certain human brains belonging to World 1 (Popper and Eccles 1977/1995: 41).[12]

Examples of other such World 3 objects which have World 1 embodiments include a plan of a building, or a design of an engine, or of a new airport (Popper 1979). As abstract World 3 entities such plans (or engineering designs) can be further modified or improved through (cooperative) criticism and they can, via World 2 (that is, via grasping or understanding by the mind), exert a causal influence upon

[11] For a discussion of how to understand the partially autonomous nature of World 3 products see Chakrabarty (2014).

[12] Such embodied objects do not exhaust World 3. Popper accepted the possibility of the existence of unembodied World 3 objects which are neither materially embodied nor do they exist as World 2 memories nor has been discovered by anyone yet (Popper and Eccles 1977/1995: 41).

World 1 (Popper 1979). Apparently, for Popper World 3 entities themselves are characteristically abstract entities (with epistemic content) but their tangible and concrete physical embodiments or realizations (without any epistemic aspect) are not parts of World 3. Popper seems to have drawn a dichotomy between the tangible, three-dimensional structure of an artefact (e.g., paper, glue, thread, cloth etc. that make up a book, say, the *Bible*) and the abstract objective content (e.g., the same text, the same sequence of sentences, the semantic and syntactic properties, that remains invariant through various editions of the *Bible*) that this structure is a carrier of.

Baird's (2004) argument for inclusion of scientific instruments directly and entirely in the Popperian World 3 implicitly challenges the Popperian intuition that the abstract World 3 entities (e.g., theories) have epistemic content, but their tangible carriers do not have any. This neo-Popperian approach of Baird does indeed raise some difficulties[13] (see e.g., Kletzl 2014) but his first-ever attempt to introduce materially constituted things or instruments as exclusively World 3 objects (because like theories or other linguistic entities they bear knowledge themselves) opens up a promising avenue for the present investigation.

The proposal of Baird (2004) for a more comprehensive World 3 (comprising of sophisticated artefacts like scientific instruments) might be extended further to include the epistemically complex but sytematically simple early stone tools in World 3. However, as Popper (1972) pointed out, if the objective, epistemic content of (linguistically formulated) theories or arguments or hypotheses cannot be explained taking knowledge as justified-true-belief, it would be equally vain to try to explore the epistemic complexity of prehistoric tools from the traditional, subjective perspective. These ancient stone tools, whatever else they might be, are obviously not some primitive beliefs or psychological states of hominin minds.

Philosophers and historians of technology or reflective engineers have rarely engaged themselves with investigations into the epistemic nature of technological artefacts exploiting the Popperian perspective of objective knowledge. Computer scientist and cognitive historian Subrata Dasgupta (1996) is the first scholar I know who profitably uses certain Popperian insights in his evolutionary account of artefacts. Like Popper he regards theories, rules, hypothesis etc. as knowledge and uses the term 'knowledge' to denote 'somewhat more than' justified-true-belief (Dasgupta 1996: 32). Though he doesn't explain any further what he means by the phrase but his discomfort with the traditional understanding of knowledge is plainly visible. More intriguing perhaps is his classification (Dasgupta 1996: 10–12) of artefacts into two kinds, namely, material and abstract. In addition to material artefacts– which belong entirely to the physical world (World 1) he

[13] Baird has been criticised (e.g., Kletzl 2014) for not providing a more plausible explanation of the problem of justification of instruments. Had he interpreted 'knowledge' in the strict Popperian sense he could have easily explained to his critics why the issue of justification whether of theories or of instruments in the traditional way is a relatively unimportant problem for Popper's objective epistemology and his 'thing knowledge.' For a review of this problem of justification see Musgrave (1974).

considers plans, diagrams, designs, algorithms as abstract artefacts belonging to the objective World 3 (Dasgupta 1996: 10–12). Though literally intangible these plans, designs etc. can be made visible through symbol structures (say, engineering drawings or mathematical equations) and these abstract artefacts are as real as the material ones because once created they can be used, analysed, communicated and modified by anyone concerned (Dasgupta 1996: 12). Interestingly, Dasgupta's portrayal of material artefacts as (exclusively) World 1 entities does not match with that of Popper but his (Dasgupta 1996: 10–12) argument for the objective reality of abstract artefacts (e.g., plans, designs) almost echoes that of Popper's for the reality of abstract World 3 objects. The problematic aspect in Dasgupta's account is, his more recent description of stone artefacts as the earliest instances of creative products bearing quite complex and original knowledge (Dasgupta 1997) is inconsistent with his earlier characterization of material artefacts as entities of the *given*, natural world, i.e., the Popperian World 1 (Dasgupta 1996).

However, for our present concern of exploring the epistemic aspect of early stone tools his (Dasgupta 1996: 150–179) profound scrutiny of technological knowledge seems extremely useful. Technological knowledge, according to him (Dasgupta 1996: 181) is itself heterogenous in nature as it includes basic sciences,[14] mathematics, formal engineering knowledge, i.e., technological theory or engineering science. But from the dawn of hominin evolution to the present day of digital technologies what continues to serve as the most significant and distinctive sources of technological knowledge is the knowledge of operational principles, that is, the knowledge of how certain kinds of structural forms and materials function, behave, perform, and appear under certain conditions (Dasgupta 1996: 157). It is this knowledge of operational principles that is common to all production of technical artefacts (from the ancient stone tools to modern space crafts). Drawing upon Michael Polanyi's (1962) original idea of operational principles he offers a more elaborate definition as follows: "…For a given class of artefacts, an operational principle is any proposition, rule, procedure, or conceptual frame of reference about artefactual properties or characteristics that facilitate action for the creation, manipulation, and modification of artefactual forms and their implementations" (Dasgupta 1996 :158). Evidently, operational principles as propositions, rules, or procedures are not any subjective, mental *acts* (or processes) but useful, analysable and modifiable objective *contents* (or products).

Let us take a glance at Dasgupta's (1996) account of operational principles before I proceed towards a closer review of the epistemic complexity of prehistoric stone tools in the next section. Robert Stephenson, the designer of the famous wrought-iron tubular Britannia Bridge (built in the 1840s) conceived the initial idea of the tubular bridge by rejecting the best-known form of long-span bridges of the time, namely, the suspension bridge form because of its insufficient rigidity. The hypothesis which possibly led Stephenson to reject the idea of the suspension bridge

[14] By stating that science is just one component of technological knowledge Dasgupta (1996) challenges the popular perception that technology emerges from science and entails the mere application of scientific knowledge.

form has been stated by Dasgupta (1996: 158) as: *Suspension bridges are not sufficiently rigid for the support of rapidly moving railway trains*. The above proposition relating the structure or form of the suspension bridge to a functional property, (namely, the ability to withstand a particular kind of dynamic load) is, in Dasgupta's (1996: 158) view, an operational principle originated from experience of the behaviour and structural capabilities of suspension bridges.

More common examples of operational principles come into sight if one reflects on how, for instance, the scientifically illiterate workers, having no knowledge of solid-state physics or of heat treatment or phase transformations in metals and alloys, forge red-hot steel so perfectly? What these workers know, Dasgupta (1996: 168) argues, are certain unwritten qualitative rules corelating the colour of heated metal to its malleability and forgeability. Such unwritten qualitative rules are nothing but operational principles. A comparison of such unwritten rules-as-operational-principles employed by workers in forging red-hot steel with what Vincenti (1984: 574) refers to as 'implicit, wordless' knowledge evident in the ability of the workers engaged, for example, in upsetting rivets may seem relevant at this point. But the reason I focus solely on Dasgupta's study of operational principles-as-knowledge is stated below.

Dasgupta (1997), unlike Vincenti (1984), gleans examples of operational principles not only from the recorded history of technological artefacts but from the archaeological data of prehistoric stone tool technology. Archaeological-experimental research (e.g., Toth 1987) documents that ancient stone artefacts (dated to be between 1.9 and 1.4 million years old) excavated at sites in the Koobi Fora district of northern Kenya, were made predominantly by a special technique, known as the hammersmith technique. This hammersmith technique is basically a procedure emerged from archaeological experiments[15] that facilitated action for manufacturing stone tools. Naturally, Dasgupta (1997: 128) considers this ancient hominin technique of tool making as an operational principle. The following section seeks to provide a closer review of what other kinds of operational-principles-as-knowledge might have generated by the making and use of these prehistoric stone tools.

5.4 Section 3: Early Stone Tools as Epistemically Complex Entities

The present section focuses on the stone tool production known as the Oldowan (Leaky 1971) industrial complex and on the early *Homo habilis* – arguably the principal Oldowan tool maker (Leaky 1971). The reason we are examining this Oldowan

[15] Operational-principles-as-knowledge may generate in different ways. The most explicit means possibly are the processes of design but experiments and experience also produce operational principles. For details see Dasgupta (1996).

stone tool production – occurred sometime between 2.00 and 2.4 million years ago – is as follows. Though *Homo habilis* might not have been the first hominin to use tools (to adapt to and survive in an unstable environment)[16] but *Homo habilis* was possibly the first bi-pedal hominin to start making tools– mostly sharp stone flakes and cobbles (see, e.g., Coolidge and Wynn 2016) – that lasted and were reusable (Jeffares 2010a: 509). The present study makes no such claim that the making and use of sharp-edged flakes is necessarily tied to the genus *Homo* but the human genus probably introduced fundamental changes in the way the brain interacts with the environment two million years ago.[17]

The Oldowan stone tools include simple core forms made on cobbles or chunks (choppers, discoids, polyhedrons, heavy-duty scrapers), battered percussors (hammerstones, spheroids, subspheroids) retouched flakes (scrapers, awls), a range of débitage (flakes, broken flakes and fragments) and unmodified stones (manuports) that appear to have been carried to sites (Toth and Schick 2018: 5). All these simple flaked and battered forms of Oldowan tools exhibit a breakage pattern known as *conchodial* fracture (resulting from high-impact percussion) and contrast sharply with the naturally broken stones found in the surrounding geological conditions. Archaeological experimentation with percussion-induced flaked stone technologies suggests two possible reasons for the adoption of Oldowan tools. Firstly, the sharp-edged flakes were probably used for de-fleshing carcasses and creating chopping or scraping edges (to produce things like wooden digging sticks or spears) and secondly, the cores might have been used for bone smashing and extraction of marrow (Toth 1987; Schick and Toth 1993). More recent studies (see e.g., Wynn et al. 2011) also attest to this possibility that these flaked-stone tools had offered the *Homo habilis* a unique way of adapting to new ecological conditions such as moving into an adaptive niche where they had to compete with large carnivores for access to animal carcasses.

To explore the epistemic complexity of these Oldowan tools one must look into their manufacturing process. But before examining the tool-making process two points need to be noted. First, Oldowan tools appeared to be the results of the intentional controlled fracture of stone by Oldowan hominins (Toth and Schick 2018: 13) and not the results of any accidental bashing of rocks. Thus these stone tools are possibly the earliest (surviving) products of hominin creation. Second, archaeological evidence about the potential uses of Oldowan tools and the cognitive-behavioural abilities required for their making are drawn from closer scrutiny[18] of these stone

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[16] Leakey's view has been questioned by contemporary scholars like Jeffares (2010a) who thinks *Homo habilis* definitely had tool using ancestors.

[17] The distinction between the tool-assisted foraging of some primates or birds and the tool-dependent foraging of the human genus that indicates a new level of integration between brain, hand and tool is worth noting here (Bruner and Iriki 2016: 4).

[18] Such scrutiny generally consists of replication of artefact- forms, followed by experimental assessment of the feasibility of performing a series of tasks with each artefact form, microscopic study of use-wear polishes, and the examination of marks made by stone tools on other materials, notably bones (Isaac 1989: 129).

artefacts and their context. This phenomenon calls attention to Popper's anti-psychologistic thesis that we can learn more about production behaviour by studying the products themselves than we can learn about the products by studying production behaviour (Miller 1995: 65). One must also be aware of the problem of 'minimum necessary competence' (Wynn and McGrew 1989: 384) – the problem that archaeologists can assess only the minimal abilities required for producing a particular pattern of tools and what their research reveals can hardly be considered exhaustive. What follows is thus a review of the insights, information (or knowledge) and abilities that were minimally required for Oldowan tool production.

From his own experiments, Leaky (1971) concluded that in order to remove flakes to create a chopper, early *Homo* had to know the correct angle at which the blow must be struck to detach a flake at the desired point in the desired direction. More precisely, in order to detach a flake from a pebble core (a) the stone needs to be struck at an angle of about 120 degrees to the direction in which the flake is to be removed, and (b) the point at which the blow requires to be struck must be near the edge of the stone. Manifestly, (a) and (b) indicating how to strike the stone at a certain angle, in a certain direction and near the edge are techniques of tool flaking (or knapping techniques) that emerged along with the stone tools themselves, as archaeological experiments suggest. Following Dasgupta (1997) such techniques may be described as operational principles.

Oldowan stone tool technology has been interpreted by Toth (1987) as a system including several stages, namely, the initial acquisition of raw material, the making, use, and finally discarding of the stone tools. More recent archaeological studies (e.g., Delagnes and Roche 2005; Stout et al. 2005; Jeffares 2010b; Stout 2011) also confirm that Oldowan tool production consists not simply of actual flaking techniques (including core examination, target selection, core positioning, hammerstone grip selection and accurate percussion) but also of acquiring raw materials of appropriate size, shape and composition. Moreover, the transport of the stone could also be added as a separate step at any point between the acquisition of the raw material and the discard of the tools. From the analysis of reconstructed cores, it seems evident that Oldowan raw materials had been tested at the source, then selected stone resources had been transported for initial flaking at a second location, and then selected flaking-products had been transported for use at a third location (Toth and Schick 2009, 2018).

Let us examine the simplest kind of stone-flaking process a bit closely. When a tool maker strikes a cobble with another, usually harder, stone (often called a hammer) this basic action produces two potentially useful products: a smaller, thin piece called a flake having a very sharp edge and a larger piece called a core from which the flake has been removed. This large piece now has a few sharper and potentially useful edges than it did before. To flake stone competently, one thus needs to constantly search for acute angles on core edges from which to detach flakes (Toth and Schick 2009; Stout 2002, 2011). This simplest kind of stone flaking appears to depend on two features: first, it depends on the control of the pattern of application of forces to a stone. A carefully controlled, sharp, glancing blow from the hammer to the core is required to initiate fracture.[19] Experimenting with the same kinds of raw materials and methods that early hominins might have used, Toth (1987) has discovered that to flake a stone in a controlled manner (i) the stone has to have an acute edge (one with an angle of less than 90 degrees) near which the hammer can strike, (ii) the blow must be struck about a centimetre from that edge, and (iii) the blow should be directed through an area of high mass, such as a bulge. Clearly, stone-flaking requires both strength in delivering blows and precision in the placement of blows.

Second, the stone-flaking process depends on the mechanics of the stone-fracture, i.e., on the internal properties of the stone. Just as the failure to apply force in the right direction will not bring the required changes to the stone even when the raw material has the required properties, similarly, applying force in the appropriate way but to unsuitable raw materials might not produce the intended result. After all, many kinds of stone are not amenable to flaking. Upon examining both the gravels in modern stream beds and those that could have been on the surface at the time of hominin occupation Toth (1987) has found that more than 90% of the cobbles in each stream bed were dark lava and the rest consisted of ignimbrite, chert and quartz. When the interior of a heavily weathered lava cobble becomes oxidized, the stone flakes unpredictably. The sign of such excessive oxidation is often a hairline fracture on the surface, known as 'weathering flaw.' Stones with such weathering flaws are commonly available at Koobi Fora but, quite interestingly, the characteristic fragments they produce are rare among the tools excavated there. The *Homo habilis* probably had some knowledge of how to identify and select lava cobbles without defects that render them unsuitable for flaking. We may note here yet another example of operational principles as 'rules of thumb' (Dasgupta 1996: 167) or heuristics (though it is far too crude than those used in human problem solving) pertaining to the quality of raw materials.[20]

In the course of his thousands of experiments at the sites of Koobi Fora, Toth (1987) has tried a range of flaking techniques such as hard-hammer percussion (striking a core with a sharp, glancing blow from a stone hammer), anvil technique (striking the core on a stationary anvil stone), and bipolar technique (striking the core with the hammerstone while it rests on the anvil). The fracture patterns on cores, flakes and fragments resulting from each technique along with the overall efficiency of the technique were also analysed by him. Comparative data show that stone tools found at Koobi Fora were made predominantly by the hard-hammer percussion technique, arguably the most efficient of the three techniques for lava cobbles. This knapping technique of hard-hammer percussion – striking a core with

[19] The controlled fracture of stone by hand is called knapping.

[20] The experiments of Stout and colleagues (Stout et al. 2005) at the early (2.6–2.5 Mya) sites at Gona, Ethiopia also suggest that the early toolmakers were able to identify and preferentially select higher quality materials (finer-grained volcanic materials with fewer phenocrysts that could produce hard, sharp edges when flaked).

a sharp, glancing blow from a stone hammer – is again an example of operational-principle-as- procedure that facilitate action for unifacial stone flaking.

Oldowan tool making is often believed to have primarily worked by producing sharp-edged flakes where the sharp edges are produced by the specific fracture mechanism called conchoidal fracture (Roche 2005). The control of flaking by means of conchoidal fracture is a fundamental aspect of the skill involved in stone-flaking. Though what is exactly required to control the shape of a flake through conchoidal fracture still remains poorly understood, skilled Oldowan tool makers seemed to know how to evaluate and control the consequence of each flaking to some extent and to modify the morphology of the core surface in a way that provides further opportunities for subsequent flaking (Roche 2005). Furthermore, Hovers' (2009) examination of flaking accidents (e.g. hinged flakes seen on cores) at the site Hadar, Ethiopia (dating to ~2.36 Mya) indicates that the hominins knew how to recover from such accidents and continue to remove potentially usable flakes from cores. Toth and Schick's (2009) research also attests to this possibility that Oldowan hominins probably knew how to identify an error (e.g., a percussion mistake) in a planned sequence, to figure out how to work around this and to change the working core for continual removing of flakes.

The above studies of the Oldowan stone-flaking process reveal different examples of knowledge-as-operational-principles (minimally required for effective stone-flaking) and seem consistent with Dasgupta's (1997) description of early stone tools as systematically trivial but epistemically complex entities. The operational principles embodied in these skilfully shaped Oldowan tools, as suggested by archaeological data, are as follows: (i) how to find appropriate angles on the edge of the cores to initiate fracture, (ii) how to strike the cores with the proper force, at the proper point of percussion, (iii) how to identify and select suitable raw materials (e.g., lava cobbles without weathering flaws), (iv) how to evaluate and control (to some extent) the consequences of flaking, and (v) how to identify an error (e.g., a percussion mistake) and correct it by manipulating the working core surface for subsequent flaking opportunities. Among these the first and second are, as per Dasgupta's (1996) classification, operational-principles-as-procedure (or technique), and the third, forth and fifth seem to be operational-principles-as-rules (e.g., rules of thumb) but all of them constitute knowledge in the Popperian objective sense – knowledge that can be examined and modified inter-subjectively independent of their subjective origins. To phrase it differently, these operational-principles-as-knowledge are neither themselves psychological entities (e.g., beliefs in hominin minds) nor are they reducible to some early form of hominin mental or psychological acts or processes.

Now the question still lurking for the present discussion is: in what sense are these operational-principles-as-objective-knowledge embodied in the Oldowan flaked-stone tools? To address this question we need to look at once more to the material and linguistic products of World 3. Popper (1979: 2) made it quite clear that World 3 comprises not only of linguistic creations such as theories, conjectures or critical arguments but also of technical artefacts like machines, sculptures, tools and computers[21] though the products of human languages (e.g., tales, myths, conjectures, theories) are the most important and basic of World 3 objects (Popper 1979). For, by formulating an idea or thought or belief in some language we make it a possible object of criticism and modification, thereby transferring it to the objective World 3. More importantly, we can make unexpected discoveries about these World 3 entities. In contrast, our World 2 thought processes or mental states being a part of ourselves cannot come under inter-subjective scrutiny. World 1 embodiments of World 3 entities (e.g., printed books, a geographical map, or a building-plan), according to Popper (1979), are important no doubt, but for being receptacles of abstract World 3 content and not for their own physical structure or artifactual forms.

The evolutionary history (e.g., Basalla 1988; Petroski 1992: Dasgupta 1996) of artefacts or artefactual forms (like bridges, steam engines, and even everyday things like pencils or paper clips), on the other hand, suggests the contrary, namely, that the tangible, three-dimensional structures of the artefacts (such as the Britannia bridge built by Robert Stephenson or the steam engine made by Thomas Newcomen) themselves are as much the products of human ingenuity and as much capable of being examined, modified and improved by others as the contents they materialize. If, as these historical studies point out, artefacts or artifactual forms (or structures) can be equally subjected to unremitting criticism and if we are ready to challenge the Popperian assumption of the intrinsically abstract character of World 3, these bridges and engines may be interpreted as belonging wholly to World 3. For, their very artifactual forms or structures are as much capable of being scrutinized, modified or deciphered by anyone concerned as is any linguistically formulated idea or thought or theory. The same argument might be extended to early stone tools.

This very possibility of being understood, deciphered and criticised inter-subjectively implies on the one hand the (partially) autonomous character of all World 3 products and on the other their irreducible difference with World 2 thought processes or mental states. One might argue further that just as theories or conjectures are not seen by Popper (1979) as 'mere' linguistic expressions of subjective mental states, similarly these stone tools also are not to be interpreted as 'mere' (epiphenomenal) residue or by-products of early hominin cognitive acts or thought processes because they embody rules and techniques (no matter how crude they are) generated during their making and multiple use. Otherwise how could modern-day archaeologists decipher so much information about how our hominin ancestors made and used stone tools more than two million years ago?[22] The inferences archaeologists draw about early hominin production behaviour (e.g., Oldowan stone-flaking techniques) are based predominantly on examination of and experiments with what is archaeologically available, i.e., the hominin stone artefacts.

[21] Many World 3 objects, though not all, are embodied or physically realized in World 1 physical objects (Popper 1978: 145).

[22] Toth (1987) has, in fact, replicated the entire range of Oldowan core forms along with a variety of flakes.

If we know for a fact that archaeological analyses of and experiments with prehistoric stone tools reveal information (or knowledge-as-operational-principles) about early hominin tool-making behaviour, then there seems something in the stone tools themselves that is epistemologically important. Just as the drawings and pictures recorded in the machine books of Agostino Ramelli or in the note books of Leonardo da Vinci conveyed a vast body of new technical ideas about machines and their operations (Ferguson 1977), similarly, these ancient stone tools themselves bear and convey quite an amount of objective knowledge (in the form of operational principles). A scar at the edge of a core, for example, gives a hint about where to strike a blow to cut a flake off; or, an acute angle on the stone indicates that a flake must have been removed from here; or, the two faces of a (late Oldowan) handaxe suggest a flaking technique that allows for successive removal of flakes from an original core. In fact, the very shape of the skilfully flaked Oldowan stone tools and their physical features bear traces of the skills, insights and knowledge-as-operational-principles involved in their manufacturing and use.

5.5 Concluding Remarks

Characteristically, the operational-principles-as-knowledge embodied in these million-years-old stone tools appear nothing more than certain extremely rudimentary forms of ad-hoc rules or techniques used by early hominins. Nevertheless, these epistemically rich prehistoric stone artefacts can be examined and evaluated by interested researchers in the same way other more sophisticated World 3 entities like scientific theories or mathematical constructions are reviewed and revised intersubjectively. We might recall one of Popper's thought experiments at this point. Popper (Miller 1995: 67–68) once asked us to imagine what will happen if long after the human race has perished a few books may be found by some civilized successors of ours. Those books, Popper (Miller 1995: 68) was convinced, may be deciphered because what makes a thing a book (an entity of World 3), is neither its composition by thinking individuals nor the fact that it has actually been read but the possibility of its being understood or deciphered. If we reformulate Popper's thought experiment and pose the following question – what will happen if long after the human race has perished a few tools or artefacts (e.g., Oldowan stone tools) may be discovered by some civilized successors of ours – the answer would not be much different. Those tools or artefacts might also be deciphered. Hence, they belong to World 3 on account of their potentiality of being examined and interpreted by others. The prehistoric Oldowan tools are possibly the earliest instances of hominin knowledge-as-operational principles that was subjected to examination and modification through successive stages in the course of an evolutionary pathway (extending over centuries) and that facilitated active hominin adaptation to the world.

It may now seem clear why philosophers and reflective engineers concerned with technological knowledge cannot afford to neglect the epistemic significance of these Oldowan stone tools. The above discussion of ancient stone tools as epistemically complex products of hominin activities would be more philosophically interesting if connected with the recent scholarly investigations into the critical impact of those stone tools on the evolution of early hominin cognitive capacities (see, e.g., Jeffares 2010a; Stout 2011; Malafouris 2013; Wynn and Coolidge 2016). I, however, leave that topic for discussion in another place.

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