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Human presence in extreme environments as a condition of knowledge: an Epistemological inquiry

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Simulations and immersive technologies have been proposed as alternatives to human presence in isolated, confined or extreme (ICE) environments, but there are limitations to these technologies and techniques that penetrate to the foundations of knowledge. Technologies of simulation and immersion, no matter the fidelity, place a barrier between the knower and the known. While technologies of simulation and immersion should be an integral part of planning and preparation for scientific research in ICE environments, the presence of a human observer in these environments will enter into the construction of any knowledge derived from such environments. Taking space science as a paradigmatic form of research in ICE environments, a conceptual analysis is made of the role of the human observer as a necessary condition of the construction of scientific knowledge.

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anthropocentrism, epistemology, knowledge, science, mesophilic norms, extreme environments, knowledge argument, Mary's room

A dangerous method

Human nature is divided against itself in the face of danger. This is familiar to us in the form of the fight or flight response, but it is equally true in regard to the dual fascination and revulsion many experience in our inability to look away from a horror. The human instinct for survival, shared with every organism in the biosphere as the foundation for natural selection, has instilled us with a strong aversion for danger and a preference for safety. At the same time, the instinct to explore is equally foundational to natural selection, and in human beings the instinct to explore took on an importance that it did not have for any other organism in the biosphere: through exploration, and with the use of technology, human beings penetrated into every biome and distributed itself as the first mammalian species with a planetary-scale distribution. Other mammalian species have followed our planetary-scale expansion, notably rats, and will likely eventually follow us in any expansion beyond our homeworld.

Again, through exploration and with the use of technology, we continue to expand our knowledge, the effort of exploration now formalized in the scientific method, which has deepened and directed our exploration and curiosity into the systematic construction of scientific knowledge, consciously pursued as such rather than merely passively acquired, as in ancestral exploration. But even the bright promise of scientific research cannot fully dispel the dangers inherent in pushing the limits of research beyond the current state of the art of knowledge so as to arrive at new scientific discoveries. Fear can be crippling, especially fear of the unknown[1], but is not inevitably so. Human fascination with danger and the unknown has overcome fear often enough to contribute to the growth of knowledge, and is now expressed in the form of scientific curiosity. Fear is linked to awe and the sublime; it is this linkage that is the source of our fascination and our willingness to overcome fear in the pursuit of knowledge. Kant had a term of this: the *terrifying sublime* (Kant, 1991).[2] Human behavior in extreme conditions, including the extreme conditions of scientific research pushed to its limits and beyond, is a function of fascination with the terrifying sublime.

The pursuit of knowledge is thus human, all-too-human. In spite of our epistemic ideals of impersonal objectivity and scientific neutrality, all scientific knowledge is formulated *by* human beings *for* human beings. This has been the case throughout history, is the case at present, and will continue to remain the case until we are able to interact rationally with other species in the terrestrial biosphere or we are able to build artificial rational agents or we encounter other rational minds that have their origins in another biosphere Until then, human beings are at the center of human knowledge, at least as the producers and consumers of knowledge, if not also as the objects of knowledge. Epistemically, then, we are not and cannot be Copernicans; human knowledge, including scientific knowledge, is anthropocentric.

That scientific knowledge is human, all-too-human is both its strength and its weakness, its value and its limitation. The fundamental humanity of scientific knowledge, even at its most abstract, makes it possible for human beings to integrate scientific knowledge into our lives, but our best efforts in science always fall short of an elusive ideal of non-anthropocentric knowledge of dubious applicability to human life. Moreover, the utility and fruitfulness of scientific knowledge—again, even at its most abstract—means that there will always be individuals who will put themselves in harm's way to make a contribution to scientific knowledge. A strict accounting of risk and benefit might never sanction placing oneself in danger for the sake of some elusive confirmation or disconfirmation of an hypothesis, but we feel in science no less than in practical life the animal spirits[3] that prompt us to action. The scientist as man the knower, *Homo sapiens*, is not necessarily *Homo economicus*, always maximizing utility and calculating an optimal outcome; science is as much a passion as an action.[4] It is when science is a passion—the passion for truth and knowledge—that even extreme environments come to be considered no barrier to scientific research.[5]

What are extreme environments?

Isolated, confined or extreme (ICE) environments, which we will, for the sake of simplicity, call extreme environments, are environments that deviate from the norms of human biology. But it would be merely circular to assert that extreme environments are extreme because they are not the ordinary environments of ordinary (human) experience. Human beings are mesophiles by definition. Environments that depart by degrees from our mesophilic norms are increasingly difficult environments for human beings to tolerate, and in which human beings experience increasing difficulty functioning, eventually requiring specialized technologies for human agents to continue to function, which includes the ability to continue to carry out scientific research in extreme environments.

The scientific study of extremophiles has prompted reflection on the distinction between extreme environments and putatively "normal" or meosphilic environments. It was been argued (Rothschild and Mancinelli, 2001) that "extreme" seems to be "in the eye of the beholder" and "based on definitions that are perhaps anthropocentric." Two alternatives to an anthropocentric characterization of extreme environments are proposed, such that "the earliest environment for life defines what is 'normal'" or that, "All physical factors are on a continuum, and extremes in the conditions that make it difficult for organisms to function are 'extreme'." But this gets us nowhere. What organisms are we to take as the baseline for mesophilic norms? If we say that this should be the conditions under which the first organisms evolved, then we are back to the second definition of extremes, by which the contemporary terrestrial environment is extremes and most organisms in it are extremophiles. Moreover, if we attempt to apply this standard to the universe at large (with no knowledge of any other forms of life and their optimal conditions), then we could with justification call human beings hyperextremophiles, since

1 H. P. Lovecraft famously stated, "The oldest and strongest emotion of mankind is fear, and the oldest and strongest kind of fear is fear of the unknown." But there is another response, which Lovecraft dismisses as, ". . .naively insipid idealism which deprecates the aesthetic motive and calls for a didactic literature to uplift the reader toward a suitable degree of smirking optimism." Shakespeare frames this more happily: "They say miracles are past, and we haue our Philosophicall persons, to make moderne and familiar things supernaturall and causelesse. Hence is it, that we make trifles of terrours, ensconcing our selues into seeming knowledge, when we should submit our selues to an vnknowne feare." (*All's Well That Ends Well*, II, 3)

2 The terrifying sublime can, ". . .arouse enjoyment but with horror," and, "Its feeling is sometimes accompanied with a certain dread or melancholy . . . " (Kant, 1991)

3 ". . .of our decisions to do something positive, the full consequences of which will be drawn out over many days to come, can only be taken as a result of animal spirits—of a spontaneous urge to action rather than inaction, and not as the outcome of a weighted average of quantitative benefits multiplied by quantitative probabilities." (Keynes, 2016: 144)

4 A sense of this passionate engagement with the pursuit of scientific knowledge, especially in regard to the 19th century, is effectively communicated in the popular history *The Age of Wonder: The Romantic Generation and the Discovery of the Beauty and Terror of Science* (Holmes, 2010).

5 Cognitive bias research has suggested that some of our biases may be "better than rational" (Cosmides and Tooby, 1994; Haselton, et al., 2015; Michalik-Jeżowska, 2019), in the sense of going beyond a strictly rational framing to account for the springs to action (or "animal spirits"). These cognitive biases are pervasive throughout our knowledge despite our attempts to eliminate them and to control for them

the conditions that obtain for the surface of Earth, while optimal for human beings, appear to be a rare exception in the universe.

We have no choice but to invoke the Protagorean maxim that *man is the measure of all things*. We have no other standard that is not as arbitrary a convention as this—no non-human or trans-human standard—for scientific knowledge. The parameters of the human being are the parameters of the scientific knowledge formulated by human beings. This anthropocentrism of scientific knowledge is inevitable for the time being. Further, mesophilic norms are geocentric as well as anthropocentric, since we are the kind of beings we are in consequence of evolving in the terrestrial biosphere.[6] An extreme environment, then, is an environment that departs from the conditions of those parts of the terrestrial biosphere occupied by human beings engaged in the ordinary business of life.[7] Extremophilic environments admit of degrees of extremity, proportional to their departure from mesophilic norms.

The aristotelian paradigm of sensory experience

Human knowledge is not limited to that which can be expressed scientifically. We often know more than we can say, know more than we can explain, and know more than we understand *how* we know what we know. Much of what we know is *tacit knowledge*, i.e., knowledge that we possess but which we cannot explain or make explicit.[8] Being able to recognize the faces of those familiar to you is an instance of tacit knowledge. One immediately recognizes these faces, and yet one cannot say how exactly one recognizes them. We can, of course, program a computer to recognize faces, and here we can say exactly how the recognition is accomplished, but this is not how human beings recognize another human face.

Only a small fragment of our knowledge is explicitly formalized. Once we arrive at a method for formalizing knowledge (and this is one of the functions of science), the process of producing and formalizing knowledge can be rendered systematic. Once made systematic, a body of knowledge takes on a life of its own, and the growth of knowledge can be pursued often without reference to the original source of knowledge in human experience. Like the use of scientific instruments to enhance and then to far surpass human senses, the enterprise of scientific knowledge at first enhances our common sense knowledge and then surpasses it. Nevertheless, human experience remains as a potential source of knowledge not yet fully exploited by science, waiting, as it were, for the insights that will capture some heretofore unappreciated and unformalized aspect of human experience that can then, in turn, take on a life of its own that grows independently of its human source.

The human body is the original scientific instrument. Science began as we explored the world with our native sensory endowment. Most scientific instruments began as instruments to augment the human senses, as in the obvious case of the microscope and the telescope, which augment the capacity of the human eye. Such instruments can grow in complexity until human senses are made irrelevant, even while the conceptual framework of the science becomes less anthropocentric by purging itself of human-specific terms and concepts.

What we know and can articulate scientifically, we largely articulate by means of evidence derived from the conventionally recognized five senses. This is a division that goes back to Aristotle, who in his *On the Soul* distinguished five special senses, which are the five senses still familiar to us today, as well as two inner senses of common sense[9] and imagination, and finally thought or intellect, which Aristotle divided in active mind and passive mind. Aristotle's account of human sensation and thought was to be the basis of faculty psychology, and the philosophical implications of Aristotle's schematization of human senses echoed through all subsequent thought, and continues to echo today. The five senses have had pride of place in our understanding of evidence of the empirical world, science came to be constructed around these forms of evidence constructed around particular sensory organs, and the larger philosophical context of Aristotle's account of the senses passed out of science even as it continued to be discussed by philosophers.

Yet as science eventually was able to substitute manufactured instruments more sensitive than the unaided senses, even the five senses became suspect. "The hard theoretical sciences had banished the eye for a long time, and many observers used to believe, and even hope, that it would remain banished forever." (Mandelbrot, 1992) Mandelbrot's claim that the eye had been banished from science can be understood both literally and metaphorically. In seeking non-anthropocentric formulations in the sciences, the human eye had indeed been banished from the sciences: the human eye was no longer needed as an instrument in science because it had been replaced by far more sensitive instruments, and in a more radical

6 I have further discussed mesophilic norms in "Cryogenic Eschatology: The Cosmological Trajectory of Life and Death" (Nielsen, 2024a).

7 This formulation can only be understood as an approximation—a rule of thumb, if you will. For example, the mesophilic norms of human life do not include living under water, but we do not for that reason refer to all fish as extremophiles. A study of extremophile fish employs the definition of extremes as, "environmental conditions considered inhospitable for most eukaryotes due to the presence of physicochemical stressors" (Riesch, et al., 2015: 2), which we could call a demographic characterization of extreme environments. Something similar, though with a concession to anthropocentrism, has been attributed to Holger Jannasch: "The term 'extreme' is based on an average range of conditions for all known forms of life, especially of the eukaryote domain with a slight anthropocentric tinge." (Horikoshi, 2016)

8 The term "tacit knowledge" is due to Michael Polanyi, whose book *The Tacit Dimension* is an exposition of tacit knowledge. The idea is developed throughout Polanyi's works

9 Aristotle's account of the "common sensibles" offers an explanation of our knowledge that does not appear to be derived from the perception of some one of the special senses: "…it is not possible that there should be some sense-organ special to the common sensibles, which we perceive incidentally with each sense. Such are movement, rest, shape, size, number and unity. All these we perceive by movement." (Aristotle, 1986: 190) It is also worth noting that Aristotle argued in the same work that there can be no other special senses than the five he described

sense the eye as a contingent relic of anthropomorphic science *had* to be banished, along with the centrality of the other human sensory organs to scientific knowledge.

The scientific account of sight and all that sight reveals to us of the world is the most advanced instance of science not only exhausting the capabilities of the human body as a scientific instrument, but of going far beyond the capabilities of the human body. The scientific account of vision has far surpassed what the human eye can see, and has become integrated with the fundamental physics that explains the electromagnetic spectrum, of which the eye perceives only a small fraction. The scientific account of vision has also become integrated with the biology and physiology that explains the details of how the human vision system functions. Thus the eye *can* be banished from science because the eye has been surpassed and superseded by science; the eye *must* be banished from science in order for science to fulfill its promise as objective, i.e., non-anthropocentric, knowledge.

Not all human senses, however, have been exhausted or exceeded by science. Our visceral sensations that reveal gravity, acceleration, and movement are less well understood, and they connect us corporeally to a different area of fundamental physics—that which falls within the purview of general relativity—which cannot yet be reconciled to the particle physics that explains the EM spectrum, to which vision gives us partial access. Thus within our own bodies we experience the division in physics between quantum theory and general relativity—except that with our body we experience the world as the seamless whole that it is, something we cannot yet do with physics.

Beyond the aristotelian paradigm: neglected senses

When we enter into a heretofore unknown environment, be it a clement or an extreme environment, we take with us not only the conventionally schematized five senses already recognized by Aristotle in antiquity, we also take with us as an integral part of our embodiment a host of senses that have not been so schematized, and for which our conceptual framework is comparatively meager in comparison to the scientific attention that has been lavished on the five Aristotelian senses. Recent research has made us more aware of these other senses, but they remain elusive even after having been named and studied. These senses include interoception (Craig, 2003), also called visceral perception (Brener, 1977) or visceroception (Ádám, 1978), and proprioception (Tuthill and Azim, 2018), also known as the kinaesthetic senses (Proske and Gandevia, 2009) or kineaesthesia (Smith, 2020).

There is no clearcut, unambiguous distinction between interoceptive experiences such as being hot or feeling hungry, having a headache or the pressure one experiences by touching anything, but which is distinct from the feeling of touch (which senses a surface and not the interior states of the human body), and kinaesthetic sensations such as the feeling of walking or knowing the position of one's hands. In some cases the two overlap; headaches, for example, are often closely associated with movements of the body. Even to attempt to name and classify all interoceptive and kinaesthetic sensations would probably run into serious difficulties. How many interoceptive or kinaesthetic senses are there? To ask to the question is to realize how inadequate our terminology and concepts are for naming, distinguishing, and numbering these sensations. Are we to identify a kinaesthetic sense for every part of the body or for every position of the body or for every kind of movement of the body? The difference of feeling between a slow, ambling walk and a fast walk that taxes our physical abilities is obvious to anyone who has engaged in these activities, but between the two lie a continuum of differentiated sensations of walking that might admit of no schematization of discrete pacing.

Interoception is moreover integral with the gut-brain axis (GBA), i.e., a function of the vagus nerve that connects the gut directly to the brain (Carabotti, et al., 2015). The human gut, itself sensed by interoception, in turn responds to the environment and, by the GBA, signals its response to the brain. For the digestion of local foods and the distinctive contribution they make to the gut microbiome, thereby influencing the GBA, there is a delay of about a day corresponding to digestion time. However, with some distinctive environments, such as micro- and zero-gravity environments, the influence upon the gut, and therefore the response of the GBA, will be immediate. Any visceral force brought to bear upon the body—flying, falling, climbing, moving (for example, being jostled along in a conveyance over a rough road on the way to a remote research location), a redistribution of weight or an unconventional body posture forced upon one (as when crawling into some difficult of access site, such as a cave)—will bear upon the sensations of the gut, and the researcher will know this, even if the knowledge remains below the level of conscious awareness.

Even the mere recognition of these capacities *as* senses was tardy, lagging far behind the recognition of natural forces perceptible only through scientific instruments, and regarded as less reliable as a consequence. These undertheorized, misunderstood, and unappreciated senses are typically ignored; no attempt is made to integrate the deliverances of these senses into scientific theory. The sensations relayed to the brain by these elusive senses is more difficult to classify than the conventionally schematized senses, and more difficult to formulate conceptually, just because the conceptual framework for analyzing these feelings is underdeveloped. But the feelings are there, and we know this when we enter into an unfamiliar environment and find ourselves responding to promptings we cannot name and do not fully understand, but which cannot be ignored. All this we bring with us when we enter into an environment, and our unarticulated sensations form the implicit background of every explicitly identified sensation that enters into scientific knowledge. As Polanyi noted, "Because our body is involved in the perception of objects, it participates thereby in our knowing of all other things outside." (Polanyi, 1967: 29).

Man *versus* machine

Everyone has had the experience of witnessing a view to which no camera can do justice, but the difficulty is more radical than suggested by the inability of a camera to capture context and to register detail. The eye is a thinking camera, and the eye that guides the hand is not only a thinking camera, but also an acting (and interacting) camera. Until we can build an instrument that thinks like a human mind, the observations of the eye will be distinct from the images produced by a camera. And the immediate feedback from eye to hand and hand to eye controls how an experiment unfolds. In a scientific experiment we are continuously aware of the reason for the experiment, its design, its construction, and its execution, all of which bring a contingent history into our awareness, the knowledge of which we retain and which bears upon our activities. Knowing that an experimental apparatus is fragile, that its replacement may be difficult and expensive, and that there may never be another chance to make these particular observations and to conduct this particular experiment, is likely to influence how we handle the experiment and its outcome. Thus not only is the *pursuit* of knowledge human, all-too-human, the *construction* of scientific knowledge is equally human, all-too-human.

The full human dimension of an experience provides context for any observation, and part of the context of any human observation is the history that leads up to the observation in question. This history of observation involves everything we do. We experience the world as biological beings of a given size and of a given temporal duration, with our wants and needs (i.e., the wants and needs of a biological being) driving us through the world and influencing what we notice and what we ignore. It is the history behind every perception that gives us our sense of our size and how we compare in size to other objects we experience, and to the contexts of our experience. When we take in any view, our awareness of our body means that everything we see, we see with the accompanying cognition of our bodies and the surrounding world within which our bodies are embedded. For example, in microscopy we are bent over the instrument, embracing it, and peering down into the eye piece, we have a vivid sense of our size in comparison both to the instrument we are using and that which we are observing by use of the instrument. The sense of size is distinct from any one particular sense (hence Aristotle could have said that the sense of size belongs to the common sense), but, if anything, it is the kinaesthetic awareness of the bulk of our bodies that is the most prominent sensory perception that shapes our sense of size, and thus our interpretation of the observation. But we experience and understand all of this and take it in stride, without spelling it out, since we have not needed to spell it out.

Every step we take, how each footfall feels, which tells us how solid the surface is that we stand upon, reminds us of our size and our solidity. When we collect a sample from the environment that we will later examine under a microscope, we bend down, touch the ground, seal the sample, and when we prepare the sample as a slide we take only a small amount of the sample and press it under another piece of glass until it is so thin that it is translucent, and thus can be lit through by the light source of our microscope. What is true of our approach to microscopy—preparing a slide, putting the slide into a microscope, and then actually viewing the prepared specimen through the eye piece—is also true of the overview of Earth from space. In an overview experience, we first see ourselves in comparison to the size of the rocket that is to take us into space, then in light of the experience of being boosted through the atmosphere into orbit, the G forces followed by micro-gravity, and ultimately looking out the window of our spacecraft—all contribute to our observation of Earth below.

Experiences such as these always occur in the context of other experiences, i.e., some experiences cannot be had with other certain experiences (mutually exclusive experiences), but the experience in question may need to appear in the context of yet other experiences (the experiences that make them possible), and these connected experiences are continuous with the knowledge we bring to the interpretation and understanding of experience. The slide must be prepared before it can be viewed. This path dependency of observation—that every observation has a context and a history that constitutes it—gives to observation meaning that it lacks in the abstract. A robotic spacecraft and its observations also have a history; there is a historicity of machine sensor readings no less than the historicity of human perception. But the historicity of instrument sensor readings is a *human* history—any and all the capacities possessed by the instrument were designed and built by human beings. But the very fact that there is this division, this divergence, between our (human) observations and the observations of the instrument that we build, means that there is a divergence between human and machine perception.

A scientific observation is presented in abstraction from these connected experiences, in isolation from the necessary concomitants of the observation, which means that science may or may not take account of the experiences that made the observation possible and which enter into the construction of knowledge. In most scientific contexts it is not necessary to belabor this connectedness of experiences, partly because it always forms part of the background of human knowledge and is never absent so long as the human being is part of the process, and partly because scientific knowledge is always abstract to some degree—by design, as this is what makes it knowledge and not mere experience or anecdote—and the construction of this abstract scientific knowledge would be hindered to some extent by an attempt to take account of all connected experiences.

The theory in theory-laden observation

It follows from the hypothesis of theory-laden perception (Holman, 1979) that our knowledge enters into our perception, transforming it into apperception (Husserl, 1983) and shaping our interpretation of it. The theories with which our perceptions are laden are implicitly understood to be constant or nearly constant influences on perception, but there is also an immediate knowledge of our contingent situation that bears upon our relationship to that which we encounter in the world. Our bulk, perhaps even weighed down by the additional bulkiness of a spacesuit, the direction in which we are facing, our feeling of being bound by gravity (subject to change in zero- and micro-gravity environments), all enter into a continuous awareness of how *we* are changing even as our perceptions are changing and as that which we are observing changes. The "theory" in "theory-laden observation" sounds like something invariant, but our moment-by-moment awareness of our disposition and directionality is as impermanent as those varieties of knowledge Plato judged to be not worthy of the name, and yet they are there as a continuous modifier on our experience. This continuous awareness of our circumstances is often the basis of the selection of observations to be used in science: often we *know* (by tacit knowledge) which observations are good observations to be retained, and which observations should be set aside as suboptimal.

We respond to the immediate promptings of knowledge as we make our way through the world without even noticing that this is what we are doing—except when we are deprived of the ability, for example, due to some cognitive failure (which throws our dependence upon knowledge into sharp relief) or due to the failure of an instrument we are using. If we were to operate sensing equipment on a distant spacecraft remotely from the ground, we would initially struggle against the limitations of this arrangement imposed upon us, but, at the same time, the plasticity of the brain (von Bernhardi, et al., 2017) and its relation to its available sensory network would continuously adapt itself to the limitations of the situation, to the extent that this adaptation is possible, thus deriving whatever data could be derived from the arrangement and in spite of the limitations. Thus our own cognitive adaptability militates against our being able to recognize and appreciate the limitations imposed upon us. But if the instrument fails, the illusion of our seamless integration with the machine also fails.

Machine "observation," that is to say, data from the sensor package carried by an automated spacecraft, is explicitly engineered around certain theories, and in the case of scientific instruments, the entire instrument may well be constructed to verify a particular theory, and is therefore engineered in conformity with that theory. In this sense, machine observations are robustly theory-laden. Theory-ladenness, however, was originally due to the nature of human perception, and what it entails for that which is perceived. But the theory-laden observations of human beings are not as rigid as that of machines. We human beings are able to re-wire and re-program ourselves on the fly, as it were. This is possible due to human neuroplasticity (von Bernhardi, et al., 2017). Machines can be re-programmed also (this played an important role in keeping the Voyager spacecraft returning relevant data over many decades), but not re-wired to the extent that human beings change and adapt to circumstances. We are still limited by the capabilities of the brain, but we have not yet tested these limitations to the point we have exhausted our cognitive capacity. So it is not just about the sensor package, it is also about the control systems for the sensor package.

The human being senses myriad phenomena that no machine can sense, because no machine has been designed and built to sense these phenomena. We cannot exclude the possibility that an instrument could be purpose-built to register some of what the human body is capable of feeling, but we do not yet have a sufficient understanding of our own capacities to do this; our theory of our own theory-laden perception is insufficient at present to explicitly engineer an instrument around these theories. This dilemma is not limited to human beings. Identifying the distinctive human sensory endowment and its interpretative cognition as unique is not to say that other species lack a distinctive sensory suite.[10] The human sensory suite is useful because we can harness it; if we could harness the senses of other species for scientific knowledge (as we already harness them for practical ends in the form of service dogs), they would no doubt give us no less of a unique and distinctive perspective upon which scientific knowledge could be constructed. At some point this may become possible, either through uplifted species (Gayozzo, 2021) or through uploading human consciousness into the bodies of other species. That being said, because the human mind and human sensory endowment co-evolved, and the human mind moreover co-evolved with language (and therefore with interaction with other minds), the observations of a human being are capable of greater discernment and can contribute more to the construction of scientific knowledge. Human perception is directed by knowledge and so directly contributes to knowledge—this is, at once, both the strength and weakness of human knowledge, to which we alluded earlier: it builds on established foundations, but remains blind to that which might be revealed by knowledge constructed on different foundations.

Scientific research in the extreme environment of space

The space environment is extreme to the point of posing dangers to human life even when precautions are taken to protect the health of astronauts.[11] Why then go to the trouble (and expense) of bringing the human body into extraterrestrial space? The human body requires oxygen, water, food, disposal of wastes (gaseous, liquid, and solid), a particular temperature range, and probably also gravity to remain healthy for extended periods of time. A human being additionally requires sleep, diversion (entertainment), and appropriate intellectual stimulation in order to achieve optimal performance for short periods of time. (These lists of bodily and intellectual needs are not intended to be exhaustive, but are presented here only to give a sense of the challenges of supporting human life in space.) Having evolved in a terrestrial biosphere in which all these resources are readily available (though some are at times contested and obtained only through competition), the human body is ill-adapted to the sterility of extraterrestrial space. In order to survive in space, all of these resources must be made available in an extraterrestrial environment. In principle, this presents no essential problem, but in practical terms this means lifting all these resources out of Earth's gravity well, until such time as there is sufficient infrastructure off the surface of Earth to provide these resources without immediate recourse to terrestrial sources—again, something that in principle presents no problems, but which in practice is a matter of great difficulty.

Because of the practical expense and difficulty of maintaining the human body in space, especially in comparison to the relative ease of operating a machine in the sterility of space, it has been argued that space science can be done most effectively and efficiently through the use of automated and remotely operated robotic probes (Goldsmith and Rees, 2022). With the financial resources to support a human presence in space becoming scarcer after the "space race" was won by the US, robotic probes have become the accepted method of doing science beyond Earth for the past several decades. These missions have transformed and are still transforming our knowledge of cosmology. While this strategy has been highly successful, it has given us a certain *kind* of science, and the science that has emerged from the use of robotic probes is not the only possible science.

10 An Immense World (Yong, 2022) provides a gratifyingly detailed account of the sensory endowment of other species and their overlap or failure to overlap, with human senses

11 I have discussed the physical dangers of space travel, and the physical courage evoked by these dangers, in "Heroic Virtues in Space Exploration: Everydayness and Supererogation on Earth and Beyond." (Nielsen, 2024b)

As we have seen, the whole person is present in scientific research, even if much of our sensation is peripheral to our intended purpose; indeed, perhaps the entirety of our bodily sensation is peripheral, and our attention is exclusively focused on the readout of an instrument that measures a quantity that no bodily organ can detect—sometimes called "squiggly line science" (Bell 2015: 247)—seemingly making the human body irrelevant at best, an impediment at worst. The presence of the whole person in making an observation matters because the human mind is, as we now say, *embodied*; the human body is the corporeal context of the human mind—and one might say with equal justification that the human mind is the cognitive context of the human body.

The embodied mind cuts both ways: there are reductionist consequences for consciousness, but there are also anti-reductionist consequences for the body (and especially for the central nervous system, which is integrated both into the body and into the world). But the idea of anti-reductionism is so unfamiliar to us that we do not have the terminology or the concepts to explain it. We can, however, begin to glimpse that evolutionary psychology has edifying as well as humbling implications—a duality that has long been recognized as a consequence of other aspects of the Copernican revolution. We are not the center of the universe or even the center of our own solar system, but we are part of something that possesses an ineffable grandeur, and our minds are part of this also. Indeed, it is our minds that grasp their own derivation from the cosmos.

When the embodied mind is placed in a position to personally observe experiences intrinsic to space science, new forms of knowledge intrinsic to space science may result, and new forms of consciousness may emerge, shaped by the knowledge. This perfectly exemplifies Frank White's description of the overview effect as, "...the predicted experience of astronauts and space settlers, who would have a different philosophical point of view as a result of having a different physical perspective." (White, 1987: 4) That one might have a different philosophical point of view as a result of having a different physical point of view was anticipated by Lichtenberg: "I have observed quite clearly that I am often of one opinion while lying down and of another while standing, especially when I have eaten little and am weary." (Lichtenberg, 1990) And, as we have seen, it is not only the external disposition of the body of the observer, its physical point of view, but also the internal disposition of the body of the observer (recognized by Lichtenberg), that bears upon the observation. If we can only fully understand the overview of Earth from space through experiencing it ourselves, and this experience involves the whole person, so that, as Polanyi noted, "[the body] participates thereby in our knowing of all other things outside," then it is this unanalyzed whole of the embodied mind that is the *differentia* between scientific knowledge and lived experience.

The knowledge argument in space science

One might hold that nothing new is learned by the personal observation of such experiences as the overview effect. There is, appropriately, a philosophical thought experiment that addresses precisely this question. Known as "Mary's room" or as the knowledge argument, the thought experiment was originally formulated by Frank Jackson (Jackson, 1998) such that a specialist in human perception studies color vision while remaining confined within a black and white environment. With an exhaustive scientific knowledge of color vision, will the individual learn anything upon being released from their colorless environment? And, if anything is learned, what can account for what has been learned? An individual might master the fundamental physics that explains the electromagnetic spectrum and the biology and physiology that explains the details of how the human visual system functions while never having had personal experience of them. The "Mary's room" thought experiment is intended to force the question of whether anything is learned when personal experience of a given phenomenon is added to scientific knowledge of the same phenomenon. There is, as yet, no consensus on the question; philosophers disagree on whether Mary learns anything upon leaving Mary's room.

As a thought experiment, "Mary's room" it is intended not to give us a definitive answer to a circumstance that is never likely to occur in fact, but to sharpen our intuitions and refine our formulations. The same could be done for the overview effect. We could easily formulate a parallel circumstance to the knowledge argument that addresses the class of experiences to which the overview effect belongs, according to which some individual has studied scientifically everything there is to know about space travel and human perception in extraterrestrial space, and then the same individual travels into space and experiences this personally. Does the individual learn anything from the personal experience of space travel?

Astronauts and cosmonaut themselves, who have personally experienced this transition from scientific knowledge of what they expect to see, to the actual first person experience, have testified to the impact of the personal experience. Alan B. Shepard, Jr said, "...no one could be briefed well enough to be completely prepared for the astonishing view that I got." (White, 1987: 197) Robert Cenker said, "Of all the people I've spoken to about the experience of space, only those closest to me can begin to understand. My wife knows what I mean by the tone of my voice. My children know what I mean by the look in my eye. My parents know what I mean because they watched me grow up with it. Unless you actually go and experience it yourself you will never really know." (Kelley, 1988; 142.[12]

If our scientific knowledge of space research is incomplete, then it is difficult to avoid the conclusion that one learns something from personal experience of a phenomenon incompletely described by science. Indeed, there is an interesting interplay between the

12 Astronaut and cosmonaut experiences might be interpreted as experiments that verify the epistemic role of personal experience explored by the knowledge argument—extending the knowledge argument to the extreme environments of space provides tests not found on Earth. Given that, "Naturally occurring extreme habitats can be regarded as evolutionary experiments that allow studying the ability of species to habituate and adapt to altered ecological conditions ... " (Riesch, et al., 2015: 1), extreme environments for research can be similarly regarded as experiments that allow studying the ability of human beings to extend scientific knowledge beyond the mesophilic norms of human life

problem of tacit knowledge and the knowledge argument. The knowledge argument might be revised so that the situation it describes only holds for mature sciences from which all tacit, folk, and anthropocentric concepts have been purged. Therefore a poorly understood experience such as the overview effect, which has not been fully assimilated to science, might be epistemically augmented by personal experience, but if we possessed an exhaustive account in the context of a mature science, the epistemic augmentation of personal experience could disappear.

Science must begin somewhere, however. Even if one maintains that a mature science is rigorously non-anthropocentric, the long road from the earliest origins of knowledge to an ideal mature formulation of knowledge in which the human element can no longer be discerned, is a road that human beings have only just begun to travel. The elusiveness of the overview effect is but a single instance of a class of results of space science in which the human observer, and the circumstances of his observation, cannot yet be eliminated without falsifying the knowledge we wish to formulate scientifically. The human observer brings to his observation knowledge what the other special sciences have not yet rendered exhaustively, so that the observer's experience, derived as it is from an embodied mind, and that embodiment coextensive with an imperfectly understood sensory suite, is a necessary condition of a philosophical understanding of the foundations of knowledge that can someday inform scientific understanding and constitute scientific knowledge.

Conclusion

Scientific knowledge gives us not the world *simpliciter*, but the world as human beings encounter it. This is the lesson of the unavoidable anthropocentrism of science. What we fail to grasp as a consequence of engagement with the world may yet be revealed to us by means we cannot now predict. For example, human beings could evolve further capacities that pick out some aspect of the world heretofore overlooked by our species as we exist at present; conceivably we could force this development through technology, but, since we would not know what we are looking for, it would be a process of trial and error—precisely like evolution, which has given us the sensory endowment we enjoy at present through trial and error. This may come across as an arbitrary limitation on scientific knowledge, but there is little we can do about this.

On the other hand, our sensory powers that have been relatively neglected are crying out for further scientific schematization and their formal integration into the process of the formulation of scientific knowledge. Here we are not at the disadvantage of unknown unknowns, but only the elusive and the poorly understood. Here we can do better. Science conducted in extreme environments may prove a spur to better understanding, and then harnessing, the sources of knowledge latent within ourselves, which may serve to bring out features of the world heretofore neglected, because we could in the past neglect them without consequence. Not only do we need to retain the human being in scientific research in extreme environments for the advance of scientific knowledge in particular disciplines such as space science, but also for science itself, as a whole, to develop and to transcend its present limitations. The way to a less anthropocentric science lies through a more careful and exacting engagement with our fallow human capacities—that is to say, through a more focused anthropocentrism.

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The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

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