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State of science: refitting the human to nature

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ABSTRACT

Environmental institutions are realising that the human-nature relationship is a tangible target for a sustainable future. Societal change of that relationship is a challenge involving modifications to both systems and human behaviours. We argue that as Human Factors and Ergonomics (HFE) focusses on relationships, interfaces and systems it is well placed to contribute. After introducing the state of HFE and nature connectedness science an analysis of areas of HFE and human-nature connectedness themes is used to consider current work and future opportunities. We conclude that despite decades-old calls to action, HFE is embedded in a dated paradigm and has had little positive contribution to the human-nature relationship. However, HFE is well placed to create sustainable communities, designed to create a new relationship with nature. To do this, HFE needs to recognise that it should move on from solely fitting the task to the human, to refitting the human to nature.

Practitioner Summary: A more sustainable human-nature relationship can be achieved through applying HFE approaches. HFE expertise in human characteristics, systems, people and technology can be applied at differing scales with various social-economic and technical factors to address key themes in our failing relationship with nature.

Abbreviations: HFE: Human Factors and Ergonomics; IPBES: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services; STAMP: System-Theoretic Accident Model and Processes; CWA: Cognitive Work Analysis; NET-HARMS: NETworked Hazard Analysis and Risk Management System; NbS: Nature-based System

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Introduction

There is growing global recognition that the biodiversity and climate crises are a product of the failing human-nature relationship (UNEP 2021). For a sustainable future it is argued that a new relationship with nature is needed. Indeed, the Kunming-Montreal Global Biodiversity Framework at COP15 (Convention on Biological Diversity 2022) includes a target to improve the human-nature connection and the need to apply a systems approach to deliver the transformational societal change has been acknowledged (WEF 2022). At a fundamental level, Human Factors and Ergonomics (HFE) focusses on interfaces, systems and relationships so is especially well placed to contribute. However, recent reviews of HFE work on sustainability show that current work doesn't tend to cover the human-nature relationship (Bolis et al. 2023; Rathore et al. 2023). While the definition and scope of green ergonomics rightly includes human-nature connections (Thatcher 2013), the HFE work to date has tended to focus on the interfaces within sustainability initiatives, such as, for example, designs to decrease waste or to increase energy efficiency. However, in this paper we show that HFE can have bolder ambitions and provide a tangible focus on the human-nature nexus and help build the human-nature connections that are the basis of a new relationship with nature. This means going beyond a focus on the design of technical fixes to address the symptoms of the failing relationship. Treating the symptoms through, for example, renewable energy and decreasing waste must obviously play a part in delivering a sustainable future, but as a root cause of the environmental crises, it is obvious that people must live more in harmony with nature. In fact, Orr (2002) argues

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that a deep connection with nature is fundamental to help motivate and sustain our commitment to any technological fixes. We argue that a more harmonious relationship with nature can be achieved through applying HFE approaches to design across society.

At present the HFE contribution to improving the human-nature relationship is limited in breadth, with much of the work coming from the Nature Connectedness Research Group at the University of Derby. Yet, this limited breadth of contribution has had significant impact, from the design of national public engagement campaigns (Richardson et al. 2016; Mental Health Foundation 2021b; Richardson et al. 2021), through dozens of citations in policy documents, to international evidence reviews calling for the approach to be applied in policy areas such as housing and education (SEI & CEEW 2022). This work will be considered in more detail later but highlights the opportunities for where HFE can contribute. While other disciplines tend to have a focus on either the human or the natural world, HFE can lead and have a significant impact on the connections. First, as with any other disciplines based in a world with a failing relationship with nature, HFE needs to realise past roads do not lead to a sustainable future. Over the past 30 years, no country has met the basic needs of its population without overconsuming natural resources (Fanning et al. 2021). In general, humans do not live in harmony with nature, we don't know what a sustainable future looks like. There is an urgent need for new solutions. That starts with a return to some fundamentals. For HFE this can be seen as extending methods for 'fitting the task to the human' to 'refitting the human to nature'.

Humans are a 'technological ape'; a species long dependent and ever more defined by its technology (Taylor 2010). However, a reliance on technology has made human society more brittle and less able to cope with internal and external disruptions (Rees 2003). 'Advancements' such as nuclear power, robotics, medicine, artificial intelligence and the Internet have made us vulnerable to the 'dark side' of these technologies (ie nuclear weapons, unemployment, bioterrorism and cyberterrorism). HFE grew from the need to fit technology to human capabilities and characteristics to make the use of that technology safe, but also more efficient and productive; resulting in the unintended exploitation (eg in mining, forestry and agriculture) of natural resources (Dempsey et al. 2018; Borz et al. 2021; Jafry and O'Neill 2000) that drives economic progress. From the perspective of the recent IPBES assessment of the values of nature, HFE supports the dominant value of 'living from nature', rather than living with, and ultimately, as nature (IPBES 2022). The HFE discipline practices human-centred design. This means that human comfort and desires are prioritised which can have unintended consequences for ecosystems (Borthwick, Tomitsch, and Gaughwin 2022). Delivering human-centred design, tends not to consider aspects beyond human life. As part of building a new relationship with nature, a sustainable future requires de-centring humans and a move to life-centred design; a shift that can place HFE approaches and expertise at the centre of delivering a sustainable future. To this end, the current paper introduces the current state of nature connectedness science before considering the discipline of HFE within this context. This progresses to a consideration of how HFE is, and can be, involved in sections related to the core areas of human characteristics, systems approaches and people and technology. Finally, the conclusions consider the contribution HFE can make with reference to previous calls for action from the HFE community.

State of nature connectedness science

In his book Biophilia, Wilson (1984) argued for an innate link between humans and other parts of nature. Coming off this base, the human-nature relationship is complex and varied. From the industrial use and control of natural resources through to caring by providing a nest box. From fear of the extremes of nature to the wonder of natural landscapes and tiny insects. From dominant worldviews of populations that affect the meaning of nature to local access to green space which provides opportunities for sensory interaction with nature. Within this complexity the psychological construct of 'nature connectedness' emerged. Nature connectedness captures people's emotional and cognitive relationship with the rest of nature, how close the affective relationship with nature is and the extent to which people feel part of nature. Nature connectedness, as distinct from nature exposure, has been found to explain psychological wellbeing better than time spent in nature (Martin et al. 2020; Richardson et al. 2021) and has been found to be approximately four times more important in explaining eudaemonic wellbeing than existing benchmarks such as socio-economic status (Martin et al. 2020).

From earlier measures developed at the turn of the century (eg Schultz 2001) to important early work developing and understanding the construct and the benefits it brings (eg Mayer and Frantz 2004; Nisbet,

Zelenski, and Murphy 2009) the area of nature connectedness has developed rapidly, from a handful of papers in the early 2000s, to dozens a decade later and hundreds a decade further still. This work established a defined and measurable construct (Tam 2013) within the fragmentation of what is meant by a positive relationship with nature (Ives 2018). Following the surge in research, the science of nature connectedness has provided systematic reviews that show the benefits of a close relationship with nature for both human (Pritchard et al. 2020) and nature's wellbeing through being a causal factor in pro-environmental behaviours (Mackay and Schmitt 2019). Supported by findings such as the sustained and clinically significant improvements in mental health through nature connectedness (McEwan et al. 2019), it is argued that nature connectedness is a basic psychological need (Baxter and Pelletier 2019; Hurly and Walker 2019). The construct is being recognised in national and international policy recommendations (Dasgupta 2021; SEI & CEEW 2022). It is also known that through the design of suitable experiences, sustained improvements in nature connectedness can be achieved (Sheffield, Butler, and Richardson 2022). Successful interventions tend to involve repeated interventions that create the conditions for people to actively engage with nature, while traditional approaches of focussing on improving knowledge about nature have been less successful (Barragan-Jason et al. 2022). However, the range of options for increasing nature connectedness are limited and there is a need to develop approaches that work at a societal scale.

An analysis of individual levels of nature connectedness across nations has also revealed the need for macro perspectives (Richardson et al. 2022b). This work has shown that the human-nature relationship is affected by the way land is used and farmed, the biodiversity of land and how people engage with land. Similarly, the analysis showed that the human-nature relationship is related to the nature of society, the consumer economy, urbanisation and intergenerational activity. However, despite some national campaigns (Richardson et al. 2016), nature connectedness interventions have focussed on local programmes often run by the nature conservation sector or developing mental wellbeing approaches (eg McEwan et al. 2019) that have informed larger projects (RSPB 2022). For transformational change, and as indicated by the country-level analysis, more system-level approaches are required. These are introduced and discussed in the systems approaches section that follows.

Returning to sustainability, a recent analysis of the evolution of HFE for sustainability used search criteria limited to HFE with 'green' and 'environmental' being the key search terms (Rathore et al. 2023), thus overlooking nature, human-nature connectedness and biodiversity. The limited published empirical work on using nature as an HFE intervention strategy (Archary and Thatcher 2022; Norton, Ayoko, and Ashkanasy 2021) has been concerned with nature exposure, rather than nature immersion or nature connectedness. Yet, people's connections to nature are seen as one of three key realms for transformational sustainability interventions, alongside restructuring institutions and rethinking how knowledge is created and used (Abson et al. 2017). This is supported by recent work which has shown that at the national level nature connectedness has a positive relationship to a nation's level of biodiversity, whereas those countries' progress towards meeting the Sustainable Development Goals (SDGs) does not (Richardson et al. 2022b). Interestingly, this was also the case with human wellbeing; higher levels of nature connectedness were related to better human wellbeing, whereas progress towards SDGs was related to poorer wellbeing. Improving the human-nature relationship can unite human and nature's wellbeing, which is a key aim of life-centred design.

Human Factors and Ergonomics

HFE is a systems discipline (Wilson 2014) and well placed to deliver solutions to these societal and global problems (Thatcher, Nayak, and Waterson 2020) through supporting complex systems thinking (Dekker, Hancock, and Wilkin 2013). Systems thinking has helped reduce harm in many domains, but rather than tackling deeper causes there remains a stubborn focus on fixing errors (Catchpole et al. 2021) and this can be seen in the focus on treating the symptoms of the failing human-nature relationship rather than improving that relationship. The fixation on visible issues is captured by a simple representation of systems thinking, the 'Iceberg Model' (Evbuoma et al. 2021). The visible events of biodiversity loss and climate warming are symptoms of unseen factors below the surface at the base of the iceberg such as our mental models, mindsets and worldviews that encompass our values, beliefs and assumptions.

This helps explain the focus on technological solutions to deliver sustainability and the difficulty of even starting to consider the mental models, worldviews and mindsets that define the human-nature relationship. This is a relationship that is shown to be failing according to measures such as human-induced loss of

biodiversity, the accumulation of toxic waste products and our warming global climate. A further symptom of this failing relationship is that systems thinking has been eroded in many urban dwellers who have been found to have a more simplistic mental model of the complex interrelationships between humans and nature (Aminpour et al. 2022). This is clearly an issue when a lack of systems thinking contributes to disasters (Davis et al. 2014). Furthermore, there is a deep fracture in the way we think about humans and nature. Through its dualistic foundations, the scientific revolution and post-Enlightenment worldview separated the concepts of human and nature (Hamilton 2002). The anthropologist Tim Ingold (2000, p. 1) describes this as '*a single, underlying fault upon which the entire edifice of Western thought and science has been built – namely that which separates the "two worlds" of humanity and nature*'.

Schooled and built on Western science, HFE often takes a positivist perspective (Dekker, Hancock, and Wilkin 2013) where 'the task' is an external element we encounter (Richardson et al. 2017). However, just as nature connectedness recognises there is no divide between humans and nature, evidence such as cognitive integration (Hollnagel 2001), shows that it is difficult to establish where the environment begins and human systems end (Dekker, Hancock, and Wilkin 2013). Although known for decades, and never abandoned by some indigenous peoples, we struggle to live a more general integrative perspective (see Reed 2009 for an application of integrative design in the built environment) in symbiosis with nature. The foundation of Western thought is taught and continually reinforced through dominant metaphors, which we reinforce further through using technological solutions in our attempts to deliver sustainability and rebalance the complex systems of nature. This consists of two reinforcing patterns. First, when we distance ourselves from nature through technology and our built environment, we reduce how we value nature. Second, as technological apes we have come to rely on introducing more technologies as the 'solution' to the problems we have created. Our solutions are constrained by our worldview. In essence we exacerbate our problems rather than releasing ourselves from an unsustainable cycle.

How HFE can be involved

In order to consider how HFE can be involved in refitting the human to nature, Table 1 presents a matrix with HFE core areas as rows and four groups of human-nature relationships shown to relate to nature connectedness in the columns (Richardson et al. 2022b); namely: extinction of nature experience, consumption and commerce, use and control of nature and negativistic factors. The resulting 12 cells in the table were used to identify areas where HFE can be involved in developing a closer relationship with nature. The broad areas of HFE will be discussed with reference to these human-nature connectedness themes.

Human characteristics – current

HFE considers a broad range of human mental and physical characteristics. Although there is some research on nature connectedness and body image (Swami et al. 2020) there is little current work related to physical characteristics in the context of nature connectedness. However, there is a general corpus of research on human responses to the natural environment, showing how nature exposure and sometimes nature immersion improves physiological responses (eg heart rate, blood pressure, muscle tension) (Agyemang et al. 2007; Miyazaki et al. 2011; Park et al. 2010). In terms of human-nature connections, research does show how 'hidden' connections between people and nature can help demonstrate that humans are indeed part of nature. There is a body of research that shows how nature impacts human physiology and helps manage emotional regulation. Viewing roses or even simply touching oak wood have been found to calm the pre-frontal cortex and increase parasympathetic nervous activity, indicating physiological relaxation (Ikei, Song, and Miyazaki 2017a, 2017b; Song et al. 2017). The amygdala, which plays a crucial role in emotion, has improved structural integrity when people live near woodlands and viewing flowers reduces amygdala–hippocampus activation, stress hormones, blood pressure and negative emotions (Kühn et al. 2017; Mochizuki-Kawai, Matsuda, and Mochizuki 2020). Furthermore, in recent years, microbiome research has shown the vital role that they play in human health, cognition and mood. This is work that challenges the separation of physical and mental characteristics and shows that humans are walking communities of microorganisms (Robinson, Mills, and Breed 2018). Each of us is an ecosystem within a wider ecosystem.

On the psychological end of this spectrum of human function a wider body of research has considered the interaction between nature and human cognition, attention, perception, affective states and particularly restoration and stress. For a review in the context of HFE see Richardson et al. (2017), but collectively, these studies confirm the physiological,

Table 1. A matrix of HFE core areas alongside the four groups of human-nature relationships shown to relate to nature connectedness.

HFE		Human-nature connectedness themes			
Areas of HFE	Content	Extinction of nature experience – eg urbanisation and ageing population	Consumption and commerce – eg technology, income	Use and control of nature – land use, biodiversity and material footprint.	Negativistic factors – barriers, eg weather, natural disasters and threats such as spiders, snakes etc.
Human characteristics	Cognition, affordances mental models. attention, perception, learning and memory, stress, arousal, motivation, individual differences, group behaviour. Anatomy, physiology, human response to the environment.	Cognitive and affective restoration; Mental models, extended cognition, situation awareness.	The battle for attention and physical material needs.	HFE often contributing to efficient use and control of nature – macro factors that impact human-nature relationships.	Human response to the natural environment.
Systems ergonomics –	Socio-technical systems, systems failures, training, human reliability, job design. analysis of systems (including process), tasks, workload (physical and mental), communication and anthropometry.	Work design, eg work-rest cycles, city design, design of transportation systems,	Socio-technical – economics systems –eg transparency in global supply chains.	Design of conservation systems, integrating conservation efforts with existing systems of agriculture and mining	Systems (especially safety systems) for managing barriers and threats
People & technology	Workplace design, information design, training, organisational design, user centred design, user-interfaces.	Design of places and spaces – biophilic design, urban design, housing design and technology mediated engagement	HFE contributing to consumption; Role of technology, eg AI.	HFE often contributing to efficient use and control of nature.	Place design to be safe from negativistic factors; Use of VR/AR.

cognitive and affective restorative power of nature. However, the frame in such work is often how physical nature connection can be used to benefit human health, it is psychological nature connection that unites both human and nature's wellbeing through improving pro-nature behaviours (Barragan-Jason et al. 2023). From a nature connectedness perspective, simply paying attention to nature is less important for the impact on restoration. Rather, attention has importance because of its role in increasing nature connectedness in a modern world where people tend not to notice nature (Bingjing, Chen, and Shuhua 2022; Richardson et al. 2021). Simply noticing nature is a key factor in nature connectedness (Richardson et al. 2022a) and prompting noticing leads to increased nature connectedness and mental wellbeing (McEwan et al. 2019). Yet, the temporary increase in noticing nature during the lockdown restrictions of 2020 shows how the return of (excessive) consumption and commerce brings extinction to the connectedness experience (Richardson and Hamlin 2021).

Human characteristics – opportunities

The recent work on the importance of noticing nature lends itself to HFE expertise in human mental characteristics, such as cognition and attention, and starts to suggest further areas where HFE can contribute to the main themes of nature connectedness referred to in Table 1. In HFE, cognition is relevant as it engages the processes involved in acquiring, processing, storing and using information to perform a task. For a closer relationship with nature and for a sustainable future that 'task' starts with attending to and noticing nature, a crucial first step in addressing the extinction of experience.

A closer relationship with nature requires nature to be noticed, but our embedded distant relationship with nature means that there is often little inclination to attend to nature, thus contributing to an extinction of experience. For example, people with a lower connection with nature tend to look less at nature and more at buildings (Bingjing, Chen, and Shuhua 2022). Whereas people who have a closer connection with

nature have enhanced attention capacity (Douglas and Evans 2022) and tend to explore natural scenes more (Batool et al. 2022), thus reinforcing their connection with nature. So, it's perhaps no surprise that the mental models of urban dwellers, surrounded by more buildings and less nature have a more simplistic representation of the complex interrelationships between nature and humans. This more simplistic understanding then limits the ability to live in harmony with nature (Aminpour et al. 2022).

From an HFE perspective this can be seen as a situation awareness issue. A reduced ability to accurately perceive and understand a situation, such as the need for a closer relationship with nature. Many people lack the fundamental skills to develop that relationship. Just as developing situation awareness is critical for safety in a range of fields, such as aviation, it is critical to developing a relationship with nature that is within planetary safe limits. HFE itself, through its researchers and practitioners is part of that situation, with the realisation of the opportunity to apply their skills to create a closer relationship with nature being the first step towards the inclination to play their part in delivering a sustainable future.

As considered earlier, these simplistic models and lack of situation awareness, link through to the often positivist perspective of HFE where terms such as 'interface' can suggest an impermeable boundary, with the task being an external element, and something we encounter (Dekker, Hancock, and Wilkin 2013). A dominant philosophical and lived notion of separation from the environment lies at the heart of the broken relationship with nature. That mind and environment operate as a coupled system (Clark and Chalmers 1998) has developed into embodied cognition (eg Clark 1997) and the notion of the extended mind. This embodied cognition and richer account of everyday interactions is becoming more accepted within HFE (Baber 2022) and provides a route to consider human-natural environment relations, in addition to providing a scientific basis to confirm that humans really are part of the wider natural world. This includes the need to move beyond the focus on system components and the importance of affordances that arise from human-environment dynamics.

The relevance of cognitive human characteristics to the extinction of experience extends into the second theme of nature connectedness represented in Table 1; consumption and commerce. Growth and affluence rely upon continuous increases in the use of natural resources and such growth is seen as an indicator of progress towards greater prosperity and happiness (Eckersley 2000). Advertising and technology in the modern consumer world fight a battle for attention among brands, but also with nature. HFE has contributed to that battle, often for the purposes of safety, but also consumer products and technology designed to capture and maintain attention. HFE researchers and practitioners should be aware of the battle for consumer attention, the role of technology and the impact both have on the human-nature relationship. Similarly, HFE has often applied expertise on human characteristics, particularly physical, to the efficient use and control of natural resources, within the mineral extraction industry for example. Once again, there is a need for awareness within the HFE community that our material footprint and land use are macro factors in individual human-nature relationships. More positively, expertise on physical human characteristics can be applied to facilitating human engagement with nature when faced with negativistic factors such as inclement or uncomfortable weather which has been shown to be a macro factor in nature connectedness.

Systems approaches – current

Proposals for achieving a paradigm shift in the human-nature relationship through a systems approach are being made. Combining the 'pathways to nature connectedness' (Lumber, Richardson, and Sheffield 2017) with a leverage points perspective (Meadows 1999) is a recent example (Richardson et al. 2020). The pathways to nature connectedness are simply five types of nature activity that need to be activated to build a closer relationship with nature. The five pathways are: (1) contact with nature through the senses; (2) emotional engagement with nature; (3) engagement with nature's beauty; (4) finding meaning in nature and (5) compassion and care for nature. The pathways have been used widely from informing national public engagement with nature campaigns (eg the National Trust and The Wildlife Trusts in the UK), to city placemaking in Plymouth, UK (Sharman and Sydenham 2021) and mental health policy proposals (Mental Health Foundation 2021a). It is interesting to note that the pathways of sensation, emotion, meaning and beauty mirror the pathways to increasing consumer consumption identified in an influential paper from 1982 (Holbrook and Hirschman 1982) and synergises with affective human factors design (Helander and Po Tham 2003). Thatcher (2012) reviewed the use of affective human factors design for sustainability, although he also noted a number of important cautions: human needs and emotional

reactions change over time, some aspects of nature (eg spiders, snakes, sharks and poison ivy) may trigger strong negative reactions (eg fear, anxiety and avoidance), and that there is a great deal of cultural and ethnic variety in responses to the same cue from nature.

After considering the societal relevance of the pathways, Richardson et al. (2020) showed how the pathways to nature connectedness could be applied at various leverage points within systems, namely, from deepest to shallowest: system intentions and values, system design and structures, system feedback and system parameters such as standards (Abson et al. 2017). This provides a perspective where the pathways can inform cultural and urban design. Interventions to improve the human–nature relationship were recommended to increase the most powerful pathways of sensory, meaningful and emotional engagement with nature. These recommendations across policy areas such as education, health, housing, arts, health and transport, targeted leverage points around system goals, design, feedback and parameters to foster closer human–nature relationships across society. The areas for action in the evidence report for the United Nations General Assembly's Stockholm + 50 meeting draw upon this work on pathways as one route towards redefining and strengthening human-nature connectedness in our social norms. Recommending, for example, education policy and curricula that are explicitly informed by pathways to nature connectedness thinking (SEI & CEEW 2022).

This work shows that the design of infrastructure, places, spaces, organisations, transport, housing and healthcare can be used to build human-nature connections. Promoting the positive relationships of meaning, emotion and care for nature while moderating those negative relationships that see the use and control of nature. HFE can contribute to this work.

HFE systems-based tools – current

Thinking of more specific systems approaches, Thatcher, Nayak, and Waterson (2020) reviewed the opportunities and constraints of using existing HFE systems-analysis tools to show how HFE might address global problems. The crisis of human-nature disconnection is the global problem addressed here and so it is worthwhile reviewing some of these opportunities and constraints as the factors involved in the human-nature relationship are many and complex. The Accimap tool is most useful to help unpack why something has gone wrong in the past, rather than make predictions about what might go wrong in the future. However, Accimap shows how to integrate the broader social and political systems into more traditional HFE thinking. Accimap could provide an approach to unpacking why the human-nature relationship has broken down leading to issues such as the extinction of nature experience. Richardson et al. (2022b) showed how country-based factors were associated with individual human-nature relationships and a systems perspective could be used to explore this further. STAMP has largely been limited to understanding safety and accident scenarios, but Thatcher, Nayak, and Waterson (2020) showed how it could be used to model and understand much larger, regional issues such as a food contamination incident. CWA has similar limitations to Accimap about making predictions, although there are new tools such as NET-HARMS which aim to extend the predictive power of CWA. Salmon et al. (2019) have also shown that one of the stages of CWA, Work Domain Analysis, can be used to characterise large systems (they considered the whole Earth system) for helping to understand global problems. Individuals, organisations and business have a role to play in renewing the human-nature relationship. Thatcher and Yeow's (2016) system-of-systems framework for HFE provides a useful theoretical structure for understanding what is missing from these complex systems analysis tools that might make them more compatible with natural system cycles. The framework shows that natural systems occur in a nested hierarchy of complexity with each system dynamically evolving over time. These aspects need to be incorporated into existing systems analysis tools.

One limitation with all HFE systems-analysis tools is their poor incorporation of non-human agents/actors (eg plants, wildlife and other ecosystem elements) other than technology and policies/procedures (which are arguably just human-designed agents/actors). A further limitation with HFE systems-analysis tools is that they fail to account for self-organisation and self-adaptation. This is particularly important for human-nature connections where all the relevant agents are adaptive, not static. Finally, Thatcher, Nayak, and Waterson (2020) noted that their study was limited because it only examined three HFE systems-analysis tools; Accimap, STAMP and CWA. They argue that it is unlikely that a single HFE systems-analysis tool will be sufficient to help resolve this human-nature disconnection crisis. Instead, Thatcher, Nayak, and Waterson (2020) propose a remixing of data-capturing methods

and systems-analysis tools that match with resolving specific issues at a local level.

Systems approaches – opportunities

Systems-based approaches are a core area of HFE, and Table 1 suggests areas where HFE can interact with human-nature connectedness themes. Extinction of nature experience (Soga and Gaston 2016) is a key factor in human-nature connectedness, there is a need for both opportunity and inclination to engage with nature to develop a relationship with it. HFE approaches can be used to increase opportunity through, for example, work design and specifying work-rest cycles that incorporate nature. Although there is a body of literature on rest breaks, few studies in HFE include nature, despite evidence of benefits for cognitive restoration (Richardson et al. 2017). HFE methods could be applied to transportation systems and urban design to ensure opportunities to interact with wildlife corridors and wilderness integration where good design can be used to afford engagement with nature.

A second broad theme of human-nature connectedness where systems approaches can be applied is consumption and commerce. The modern consumer world has been built on exploitation of natural resources with no nation that meets the needs of its population doing so in a sustainable way (Fanning et al. 2021). The 'success' of this socio-technical and economic system, as indicated by average income and adoption of new technology, has been linked to greater disconnection from nature (Richardson et al. 2022b). As all governments, organisations and business have a role to play in delivering a sustainable future, HFE practitioners should be aware of these relationships and explore systems approaches to overcome the current issues. For example, this might involve enabling transparency in global supply chains so that business and consumers can make decisions based on where products come from and the impact on natural resources, climate and biodiversity.

The third broad theme of human-nature connectedness where systems approaches can be applied is the use and control of nature that has exploited natural resources and led to the climate and biodiversity crises. It can be argued that HFE as a human-centred discipline is anthropocentric and has generally, and through efficient systems design, often contributed to more efficient use and control of nature to achieve the goals of the human species (Thatcher, Lange-Morales, and García-Acosta 2020). HFE's world and systems view needs to be extended to include more than the human world, to be aware of the ecosystem that humans are part of. In their paper on HFE values for a sustainable world, Lange-Morales, Thatcher, and García-Acosta (2014) noted six values with Respect for the Earth being the first (and by implication the most important) value, since without the ecological services that Earth provides, life cannot be sustained. Therefore, even as a discipline focussed on human-centred design, we need to de-centre humans. Perhaps this might mean a shift for the HFE community akin to the sun replacing the Earth at the centre of the solar system! However, HFE is, or should be, more about relationships and their design, the way people interact with other elements in a system, since nothing exists in complete isolation. An essential shift is needed that will open new avenues of work, inputting into the design of systems of land use and integrating habitat creation into existing systems of agriculture and mining to contribute to reducing the extinction of experience. One advantage of the HFE systems methods is that they can accommodate this shift to de-centre humans, through representing values in design. For example, in CWA a closer human-nature relationship can be represented as a specific system purpose or value in the second level of the abstraction hierarchy.

The final broad theme of human-nature connectedness where systems approaches might be applied is negativistic factors. The natural world can be off-putting owing to inclement weather, or threatening owing to natural disasters and threats such as spiders and snakes. The scope for HFE systems input is perhaps limited, but still remains with, for example, effective systems for managing barriers to human-engagement with nature through helping people plan for that engagement in environments with more threats (eg working with various types of forecasts to provide more readable and interpretable outputs that also represent the uncertainty and risk). Or it might mean simply work design that accounts for access to nature in seasons that are darker, colder, or wetter.

People & technology – current

The final core area of HFE is people and technology. Technology is an important factor in nature connectedness. This is no surprise since humans are technological apes, increasingly shaped by technology, such that as technology progresses, nature becomes more distant. Analysis of the decline of nature words in cultural products has suggested that the arrival of new

technologies mirrors this decline (Kesebir and Kesebir 2017). Smartphones provide an example of how technology shapes the human-nature relationship with higher smartphone use linked to a weaker relationship with nature at both the individual and national level (Richardson, Hussain, and Griffiths 2018; Richardson et al. 2022b).

The core area of people and technology includes the design of workplaces, information and organisations. HFE's current engagement in nature connectedness specifically through these areas is limited, although it has been noted how HFE and a socio-technical approach is an ideal discipline to transform workplaces so that they tap into the benefits of nature (Norton, Ayoko, and Ashkanasy 2021). The broad area of design that takes a nature-centred approach is known as Nature-based Solutions (NbS), which uses an integrative approach to the various components of ecosystems to promote conservation and equitable use (Cohen-Shacham et al. 2019). There is only one published empirical study in HFE which adopts an NbS approach (Thatcher, Metson, and Sepeng 2022). NbS also includes work involving HFE in biophilic design. Biophilic design is originally a building design approach to increase occupant connectivity to the natural environment (see Kellert 2005). Although the basic principles put forward in the pioneering work of Stephen Kellert and Elizabeth Calabrese (Kellert and Calabrese 2015) include the need to foster engagement, emotional attachment and positive interactions, they are often overlooked. Unfortunately, biophilic design is often reduced to material and physical elements for inclusion that can be 'ticked off' checklists (Richardson and Butler 2022). This fundamental need to interact with biophilic designs has been noted as an area where HFE can contribute (Thatcher 2013). Indeed, a framework for combining the pathways to nature connectedness and principles of biophilic design has been created (Richardson and Butler 2022). There are also only a handful of examples in HFE that have considered biophilic design (see Obiozo and Smallwood 2018). In general, HFE has paid insufficient attention to nature and workplace design, despite these calls (Lumber, Richardson, and Albertsen 2018).

As noted earlier, the focus of HFE work on People and Technology is focussed on successful technology, which ultimately wins the battle for attention, increases consumption and depletes the natural world. HFE can be seen to be facilitating the safe and efficient rise of the technological ape and its use and control of nature. However, technology will continue to develop and must be integrated into developing a closer relationship with nature. For example, now ever-present smartphone technology has been used to prompt people to engage with nature for positive effect. McEwan et al. (2019) developed a smartphone app that tracked user's movements and prompted them to notice and record the good things in nature when near green spaces in Sheffield using around 1000 'geofences' in the city. This approach targeted moments outside since the vast majority of time is now spent indoors and directed attention towards nature as less connected people tend to turn their attention to the built environment (Bingjing, Chen, and Shuhua 2022). Indeed, the study found that people who spent less time outdoors and had lower baseline nature connectedness scores improved more on nature connectedness measures. Overall, the study found statistically significant and sustained improvements in mental wellbeing one-month after being prompted to notice nature. This improvement in wellbeing was partly explained by significant increases in nature connectedness. For those living with a mental health difficulty, clinically significant improvements in quality of life were also found.

People & technology – opportunities

The design of places and spaces is a key area where HFE knowledge and skills can contribute to tackling the extinction of nature experience. The pathways to nature connectedness provide a design framework that highlights the type of activities, places and spaces we should encourage. HFE methods can be used to integrate them into urban, housing and workplace design, with information design providing actionable knowledge and essential feedback on progress. This includes green spaces that are designed for engagement and to unite both human and nature's wellbeing.

One example is the HFE fundamental, affordances, which should be considered for both their positive and negative consequences. For example, on the positive side affordances can be considered in the design of natural playgrounds to create intriguing opportunities for play that can create meaningful relationships with nature (Laaksoharju and Rappe 2017) or help form a sense of place (Raymond, Kyttä, and Stedman 2017). However, affordances also need to be considered critically as they can lead to unintended negative consequences for nature such as the provision of parking and easy access leading to natural spaces becoming simply dog-walking places

which brings other negative ecological impacts (Richardson 2023; Hughes and Macdonald 2013). Beyond places and spaces, organisations need to be designed to foster a new relationship with nature. From initiatives such as B-Corps, 'nature on the board', to wellbeing programmes based on a one-health perspective.

The role of advancing technology is also an important consideration. Humans are increasingly defined by their technology and this has been linked to a more distant connection with nature. However, recent research has shown that virtual and simulated nature can have positive health and wellbeing effects (Browning et al. 2021; Reese, Stahlberg, and Menzel 2022). Technologies such as Virtual and Augmented Reality can help overcome access issues (eg for care home residents or people living in highly urbanised settings), negativistic barriers (eg acclimatisation to feared environments), in educational settings where travel to enriched natural environments are inaccessible, or simply to provide exciting opportunities for enhanced experiences in our depleted natural world that rival the virtual realities that are increasingly available in the home. In addition to virtual reality facilitating or replacing sensory nature contact, technology can enhance other pathways to nature connectedness. For example, through enhancing emotional responses and meaning of nature. Technology can create important feedback loops that make nature 'present' and foster engagement. Through embedded sensors, for example, technology can bring the life, state and condition of wildlife into people's everyday stream of information and news. Somewhat paradoxically, Artificial Intelligence and robotic personal assistants open a new world of nature engagement with technology itself guiding people back into nature, always knowing the way, what to see and how to enjoy it – safely.

Conclusions

The matrix of HFE core areas alongside the themes of human-nature relationships that has shown to relate to nature connectedness has provided a means of considering how HFE is currently involved in the human-nature relationship, but also the opportunities for greater involvement in fostering the new relationship with nature that is aimed at addressing the environmental crises of climate warming and biodiversity loss.

When the main themes of nature connectedness are considered, it can be seen that HFE has had little positive contribution to addressing the extinction of nature experience. Indeed, the consumption and commerce that control nature suggest that HFE could be part of the problem through the design of compelling technological user experiences and the efficient exploitation of natural resources. In this respect the HFE discipline is no different to the other areas of the modern world that have contributed to our environmental crises. Of course, this is not a new observation, in the mid-1990s Moray noted how HFE was a world of liberal capitalism focussed on the concerns of industrialised societies (Moray 1995). Moray was clear about the ecological issues and the need for change, and the opportunities for HFE, but concluded that he did not expect that change to come. Almost three decades on, his vision of the issues and response is, sadly, impressively correct.

Although HFE benefitted from this visionary early call to action, it has done little to make a difference on environmental issues, which, at their heart, are caused by the broken relationship between humans and the rest of nature. Consider the 2008 special issue on the 'The Future of Ergonomics' (Stanton and Stammers 2008), which had limited reference to sustainability (Haslam and Waterson 2013). Haslam and Waterson's (2013) special issue on ergonomics and sustainability notes HFE activity in this area as 'limited and tentative'. Similarly, the 2017 State of Science paper on ergonomics and global issues (Thatcher et al. 2018) highlights the lack of progress since Moray's visionary and dystopian address at the 12th Triennial Congress of the International Ergonomics Association. The challenges presented by Thatcher et al. (2018) focussed on treating several symptoms of the environmental crisis, which are ultimately symptoms of the underlying causal issue – the fractured relationship between humans and the rest of nature.

Despite highlighting the natural synergy between HFE and sustainability for many years, we must try again. Haslam and Waterson (2013) note the need to move beyond stating the relevance and the opportunity to apply the existing body of knowledge for a sustainable future. Once again, this paper highlights the relevance and opportunity, but differs by moving beyond treating symptoms to target the root cause of the environmental crises, the human relationship with the rest of nature. It also highlights how the pathways to nature connectedness provide a design framework that is already being widely used and applied, albeit in publications that are mostly outside of the HFE field.

The application of that framework to target human connection with the rest of nature can be taken much further. HFE is well placed to consider the systems

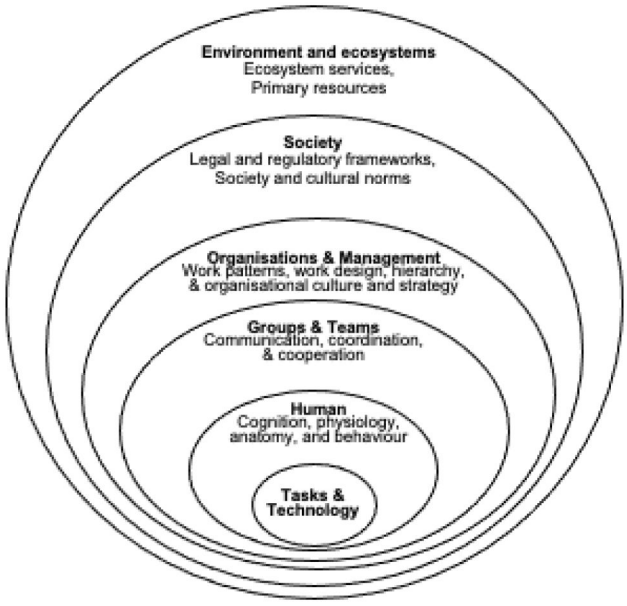

Figure 1. Reconceptualisation of Moray (2000, 861) including environment and ecosystems as an additional external layer.

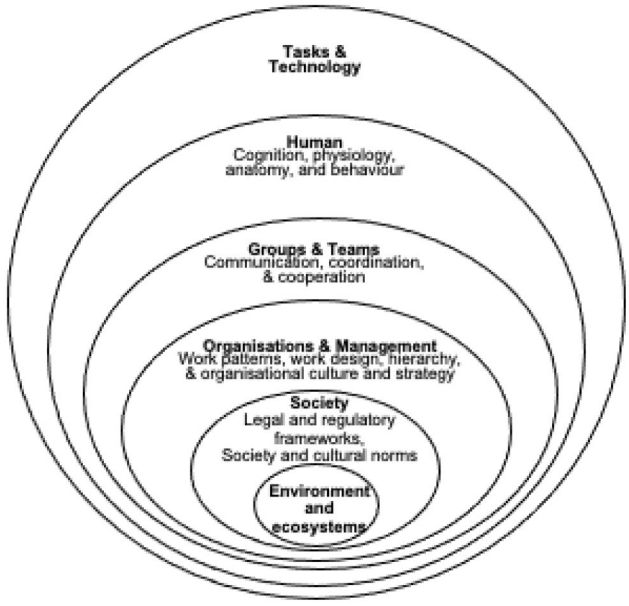

Figure 2. Reconceptualisation of Moray (2000, 861) with the centrality of the environment and ecosystems in HFE considerations.

context and to work at differing scales with various social-economic and technical factors. Within that context, HFE can help create opportunities for a new relationship with nature. It is important that those opportunities include purposive actions that allow active engagement with nature and natural systems, with feedback on progress. This application of systems thinking should include the opportunity to design in positive feedback loops. The wellbeing benefits from nature connectedness will mean that humans will come to value nature more and seek out additional opportunities to connect with nature, deriving further wellbeing benefits and leading to greater pro-nature behaviours.

Finally on implications for HFE, this means we urgently need to engage along three interrelated avenues: (1) De-centring humans by emphasising our genuine place in the broader natural ecosystem; (2) Deciphering and re-aligning our mental models, worldviews and mindsets that inhibit deep human-nature connections; and (3) Designing to (re-)connect humans to nature in a regular and safe manner. One way to incorporate this, and this paper's wider thinking into HFE is to extend Moray's (2000) 'systems' diagram of HFE to include the environment and ecosystems as a boundary layer within which all HFE interventions must operate. This representation is shown in Figure 1. While Figure 1 has the advantage of placing the environment and ecosystems as the boundary conditions for HFE considerations, such a graphical representation is antithetical to the central argument in this paper which contends that humans must be de-centred in HFE. Humans don't just live 'in' nature, we 'are' nature. We are biological entities that must co-exist in equilibrium with other biological entities or face the consequences of destabilised ecosystems. Our sustained existence demands that we find equilibrium and to do this means recognising that we are a peripheral, not a central, layer. An alternative conceptualisation that de-centres HFE is shown in Figure 2. This conceptualisation sees the design of human tasks, technologies and activities as the boundary conditions for supporting the environment and ecosystem services.

HFE provides the expertise to create visons of sustainable communities, designed to create a new relationship with nature through applying the IPBES relational values: to live from, with, in and ultimately as nature. To achieve this HFE needs to take an unlikely step, to recognise that it should not be human-centred. That cognitive flip of de-centring humans to being part of nature, both as a person and a professional, would facilitate a meaningful contribution to a wider new relationship with nature for a sustainable future. Life-centred design unites both human and nature's wellbeing. It is time for HFE to move on from solely fitting the task to the human, to include refitting the human to nature.

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