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Threshold concepts and sustainability: features of a contested paradigm

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Abstract

Threshold concepts describe the core concepts that people must master if they are to effectively think from within a new discipline or paradigm. Here, I discuss threshold concepts relevant to the science and practice of sustainability, unpacking the persistent challenges and critiques that sustainability has faced over the decades. Sustainability is immensely popular, but also endlessly critiqued as being naïve, vague, and easy to co-opt. I argue that these challenges can be traced to sustainability's status as a robust, alternative world view to the industrial, neoliberal paradigm. The threshold concepts discussed below are troublesome, and new learners face significant challenges when trying to learn them and move into the paradigm. Here, I review five threshold concepts that are widely discussed as important to sustainability: complexity, collaborative institutions, multiple ways of knowing, no panaceas, and adaptability. This list is not intended as comprehensive but exemplary of sustainability as a pluralistic paradigm. Recognizing the special status of these and other threshold concepts within sustainability, and the linkages and dependencies among them, is an important advance for sustainability education and practice. I also offer some suggestions on classroom activities that have proved effective in helping people through the process of learning these concepts.

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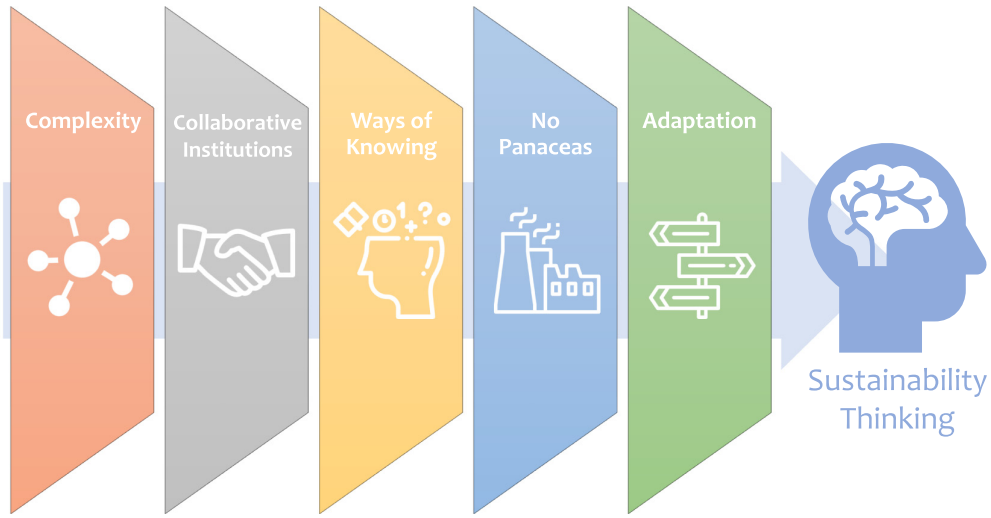

Key words: complexity, paradigm change, sustainability education, sustainability science, transdisciplinarity, transformative learning

Introduction

The concept of sustainability has seen widespread adoption since it became popularized on the world stage by the United Nation's Brundtland commission (Brundtland 1987). In Edwards' (2005) words, sustainability has created "a pervasive and permanent shift in consciousness and worldview, affecting all facets of society" (p. 2). Today, organizations at multiple levels, from community health centers to the World Bank and even a major journal (*Nature*), use sustainability as an organizing concept for their missions and activities (Goldman 2004; Nature Sustainability 2018). Likewise, numerous governments and nongovernmental organizations have signed on to an unprecedented shared vision for 17 global sustainable development goals (SDGs), each offering specific targets for action on a diversity of societal and environmental issues, from poverty to overfishing (Sachs 2012).

Yet, sustainability has also been regularly criticized as being impossible to define and easy to co-opt (Dernbach and Cheever 2015; Nature Sustainability 2018). Years ago, Solow (1991) called sustainability "essentially vague," "glib", and "faintly phony" (though still argued it could be useful). Despite setting the tone for the last three decades, the Brundtland (1987) report has been repeatedly dismissed, and many of the sustainability initiatives that followed Brundtland have indeed failed to achieve paradigmatic change, neither fully incorporating ecological concerns nor sufficiently shifting the focus of development from uncapped economic growth to growth in human well-being and justice (Sneddon et al. 2006; Burns 2012). In some cases, sustainability initiatives have become a venue for displacing local people's voices and visions for development (Brosius 1999). Greenwashing—where people use the language of sustainability to mask business as usual—is also rampant (Ramus and Montiel 2005; Cherry and Sneirson 2011; Lyon and Montgomery 2015). And, climate change, biodiversity loss, and poverty, perhaps the three most pressing sustainability issues we face as a species, have all continued relatively unchecked despite the apparent worldwide turn toward sustainability (IPCC 2018; IPBES 2019).

Perhaps owing to this mixed track record as well as the looming spectre of climate change, there has been a noteworthy retreat from sustainability in recent years, in favor of more reaction-oriented frameworks like resilience (Yanarella and Levine 2014; Dernbach and Cheever 2015). In this essay, I argue that these ongoing challenges are not fundamental failings of sustainability, but rather, are symptomatic of how fundamentally different the sustainability world view is from the mainstream, modern way thinking (Burns 2012; Dernbach and Cheever 2015). Sustainability isn't just a new concept that can be added to existing ways of thinking and managing; it is a new paradigm altogether, one that seeks to correct multiple epistemological errors in industrial and neoliberal ways of understanding the nature of human–environment interactions (Bateson 1972; Sterling 2004; Burns 2012). Sustainability is also a pluralistic paradigm, in that one of its key strengths is that it can mean different things and be envisioned different ways by different groups of people (Kates et al. 2005).

Moving from one paradigm to another can be very difficult (Kuhn 1970), as several challenges can emerge when people are learning to think in a fundamentally new way. These include becoming lost in the vastness of the new paradigm, underestimating complexity, over-moralizing concepts and their implications, and conceptual turf-staking (Wilson 1963). Each of these challenges can be observed in the academic literature and public discourse on sustainability, for example, in the perpetual debates over the merits of "weak" and "strong" sustainability (Pelenc and Ballet 2015), arguments that sustainability is being used as a trojan horse for socialist and globalist agendas (Fajack 2014), and the

relentless, uncritical pursuit of economic growth and technological innovation as panaceas for addressing environmental problems (e.g., Asafu-Adjaye et al. 2015).

To understand the challenges that people face when trying to move into the sustainability paradigm, I introduce threshold concepts: an idea developed in education research for understanding student success with learning a new way of thinking (Meyer and Land 2006; Sandri 2013). Threshold concepts describe the core set of concepts that anyone must master if they are to effectively think from within a new paradigm. To a newcomer, threshold concepts can seem counterintuitive, and learning them can be far more complicated than merely mastering certain facts or equations. Below, I present five threshold concepts commonly mobilized in the sustainability literature that, over the last decade of teaching sustainability, I have seen students struggle with as they try to explore the boundaries of this new way of seeing the world. In each case, teaching these threshold concepts requires not just repeated explanation, but the creation of transformational opportunities for students to move through the transitional, liminal space that separates old and new paradigms (Burns 2018). I offer these five concepts not as a comprehensive set but as exemplars of the sustainability paradigm's pluralistic nature, which contrasts starkly with the more rigid and easy to define neoliberal and industrial world view. I conclude with thoughts on how sustainability education and practice can benefit from this framing.

Threshold concepts

Threshold concepts function as doors or portals that give the learner access to a new way of understanding the world (Meyer and Land 2006, 2005). Generally, these doors only open one way; that is, once threshold concepts are fully learned, the learner cannot easily return to seeing the world only through the previous paradigm. To a person already within a paradigm, threshold concepts anchor their current way of thinking—they are the unspoken assumptions that most people accept as features of reality. When someone unfamiliar with the paradigm encounters a new threshold concept, however, the concepts can be troublesome—appearing counterintuitive, alien, and in some cases, entirely nonsensical. Because threshold concepts constitute the framing of a different way of seeing the world, people with a stake in the current way of seeing things can interpret them as ignorant or even as a threat. That is not to say that threshold concepts are necessarily gateways from lesser to more advanced ways of thinking; rather, they simply indicate important discontinuities among different ways of seeing and knowing the world (Nicolescu 2008).

Threshold concepts share several key criteria that make them relatively easy for educators to flag (following Meyer and Land 2006): (*i*) they are transformative, in that they create a significant shift in a learner's understanding; (*ii*) they are irreversible, in that the change of perspective that they facilitate is unlikely to be forgotten or unlearned; (*iii*) they are integrative, in that they expose previously hidden connections and help explain phenomena in new ways; (*iv*) they are sometimes bounding, meaning that they help define the limits of a perspective or discipline; and as already noted (*v*) they are troublesome, which means that they often provoke lively debate because they reject or redraw boundaries and deviate from the basic assumptions of the existing paradigm. Note that Meyer and Land (2006) acknowledged that not all these criteria must be met for something to be considered a threshold concept. By way of example, I briefly discuss three threshold concepts from the fields of economics and anthropology.

In economics, an important threshold concept is opportunity cost: the notion that all decisions involve the selection of one option and rejection of some set of mutually exclusive alternatives. To put it another way, opportunity cost is the cost paid when a decision is made, reckoned as the highest value of the various forgone options. Opportunity cost expands economic understanding of how people make decisions by positing a causal connection among scarcity and individual choice. That is, opportunity cost

characterizes all decisions as trade-offs, where people's ultimate selection of one option is influenced by the quality of their knowledge about the costs and benefits of the alternatives, both now and in the future. Thus, opportunity cost is transformative for the field of economics because it creates a basis for evaluating and comparing the rationality of different people's actions across both space and time.

A second threshold concept, from anthropology, is cultural relativism. This is the idea that a person's beliefs, values, and practices can only be fully understood from a position within that person's culture. Cultural relativism holds that cultures each have an internal logic that makes it impossible to judge the values, goals, and actions of people from one culture against those of another. Cultural relativism opens the door to recognizing multiple different kinds of rationality; Harris (1974), for example, highlighted the concept with his study of the economic and social benefits of cow reverence among the Hindu, which some outside economists had previously labeled as an irrational behavior. Cultural relativism is troublesome to the notion of economic rationality because it bounds rationality within specific cultural contexts and reveals how the basis for decisions cannot be understood only as a matter of opportunity cost. Cultural relativism is also troublesome, because it argues a cultural basis for purportedly universal notions like human progress and morality.

A final example of threshold concepts is social constructionism, which holds that the fundamental nature and meanings of observed phenomena are not objective but generated socially through interactions with others and often through the lenses of power and privilege. Social constructionism requires that we see all manner of phenomena—race, gender, natural disasters, even science itself—as constructions of social processes and discourses, not merely products of physics or biology. Social constructionism, thus, expands the boundaries within which we seek to understand biological and physical phenomena, and is troublesome both because it highlights the systemic roots of racism and sexism in society, and also because it proposes limitations to the strictly positivist philosophy for understanding the world around us.

Five threshold concepts for sustainability

Scholars working in such fields as environmental and sustainability education (ESE), education for sustainable development (ESD), and transformative learning, have done much to explore the paradigmatic nature of sustainability and how sustainability education can facilitate an ethical and epistemological transformation of our world views (Vare and Scott 2007; Lundholm and Plummer 2010; Sterling 2011, 2004; Barrett et al. 2017; Burns 2018). In part, this involves looking at the experiences, tasks, and resources that students need to envision and enact sustainable change in society; researchers in such areas as complexity science and resilience, for example, are exploring ways to introduce students to new and novel ideas related to sustainability (e.g., Ban et al. 2015; Armitage et al. 2019), but this work could benefit from further engagement with the lessons and theories from the robust fields of education research noted above (e.g., Lundholm and Plummer 2010). What that literature tells us is that teaching sustainability in theory and practice also requires a meta-level exploration of education as a transformative and relational process (Lange 2018), one that begins with both teachers and students learning to recognize, and then unlearn and replace, the dominant ways of seeing, learned in the classroom as well as through our day-to-day experiences, that contribute to sustainability problems in the first place (Barrett et al. 2017; Burns 2018, 2015).

This is a challenge with which I am, and have been, keenly engaged; since 2009, I have taught or cotaught a total of 25 undergraduate and graduate classes that directly incorporates sustainability science into the course plan and learning outcomes. In this time, I have encountered multiple concepts from sustainability research and practice that students struggle with and that fit the criteria or threshold concepts noted above. Relatively few scholars have explored the role of threshold concepts in sustainability education and practice; Sandri (2013) and Barrett et al. (2017), are examples of noteworthy

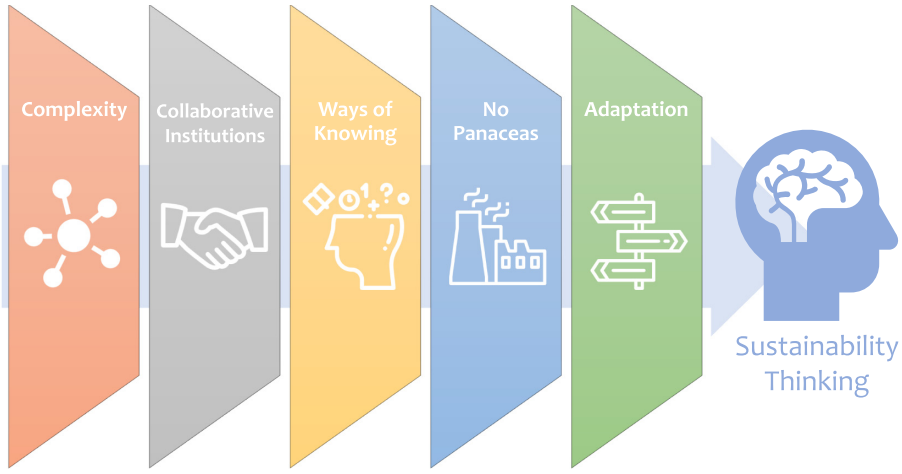

Fig. 1. Threshold concepts function as doors, or portals, to a new way of thinking. In the sustainability paradigm, complementarities and linkages exist among the five threshold concepts reviewed here that may determine whether sequential or parallel approaches to learning these concepts are desirable.

innovators in this area. Here, I discuss five key threshold concepts for sustainability, each of which are well established as being central in the sustainability science literature (**Fig. 1** and **Table 1**). I do not suggest that these five are uncontested, neither that they are the only or most important threshold concepts in the world of sustainability science and practice. Rather, I use these as exemplars of the troublesome nature of sustainability and its plurality as a way of seeing the world. These five concepts also illustrate how sustainability education and practice must direct attention to the transformation of people as well as of people's relationships with one another and with the rest of the natural world.

Complexity

The modern, industrial way of thinking is reductionist and mechanistic in nature (Bateson 1972; Ackoff 1979). That is, it teaches us to expect to be able to understand any natural phenomena as the result of a simple chain of events—an assembly line of cause and effect that leads to the outcome of interest. The assumption is that the world is inherently predictable and decomposable: any system can be understood simply by breaking it down into its constituent parts. In recent decades, this way of understanding of the world has been proved to be incomplete, and social systems for production and resource management built upon often have unintended consequences and cause runaway environmental damage (Degnbol and McCay 2007; Ostrom 2009). By comparison, recognizing complexity—systems thinking as it is often called—involves replacing mechanistic thinking with an emphasis on multiple interactions between components in a system (Berkes et al. 2003; Meadows 2008). Recognizing complexity is a shift from seeing phenomena as the additive consequence of a causal chain, to seeing them instead as the result of feedbacks and interactions among multiple drivers and constraints that collectively create emergent outcomes—where the whole of the complex system is greater than the sum of its parts.

As a threshold concept, complexity is transformative because it empowers one, through systems thinking, to see previously unexpected connections and anticipate unintended consequences of one's actions (Sandri 2013). Likewise, it is irreversible because once one comes to see the world as a set of systems, it is difficult, if not impossible, to do otherwise. As such, complexity and systems thinking are troublesome because they lead us to challenge the far more common simplistic approaches to solving societal challenges and managing our relationships with the natural world. Culturally,

Table 1. Threshold concepts in sustainability.

Threshold concept	Replaces	Summary	Key citations	Key activities/concepts
Complexity	Simple, mechanistic understandings of causality	The world as a collection of systems, in which outcomes are greater than the sum of the parts	Sandri 2013; Sterling 2004	**Concepts:** Feedbacks, emergence **Activity:** Short videos of starling murmurations (National Geographic 2016), puppies drinking milk (Gann 2013); connection circle activity and causal-loop diagramming of everyday complex systems (Quaden et al. 2008)
Collaborative institutions	Atomistic, flawed understanding of human nature	People are collaborative by nature and can develop shared systems for behavior	Ostrom 1990, 2009	**Concepts:** The great forgetting (Quinn 1996), prisoner's dilemma (Rapoport et al. 1965), formal and informal institutions **Activities:** Modified, "Red/Black" prisoner's dilemma game with opportunities to negotiate; human history timeline
Multiple ways of knowing	Positivism; there is a single "reality" that is knowable only through the scientific method	There are multiple levels of reality, each knowable through different, simultaneously valid knowledge systems	Berkes et al. 1995; Cash et al. 2003; Berkes 2008	**Concepts:** Transdisciplinarity (Nicolescu 2008), social constructionism, post-positivism **Activities:** Epistemological self-inventory and stretching; folk taxonomy card sorting exercise; creative nature connection activities and exploration of epistemic hegemony (Flowers et al. 2015; Harmin et al. 2017)
No panaceas	Technological fixes exist that are scalable and widely deployable	Solutions to social and environmental problems must fit with local culture and ecology	Kottak 1990; Ostrom et al. 2007	**Concepts:** Unintended consequences, over-innovation (Kottak 1990); ludic and industrial fallacies **Activities:** Case studies of cats in Borneo (Klimek and AtKisson 2016), grazing in Ireland (Dunford 2002)
Adaptability	Sustainability is a matter of seeking and managing for stability	Sustainability is a process of managing change; stability is an illusion, the product of change at smaller and larger scales	Adger et al. 2005; Cinner et al. 2018	**Concepts:** homeostasis, panarchy, resilience **Activity:** Thermostats and predator–prey discussion; resilience assessment of simple and diversified fisheries (Resilience Alliance 2010)

Note: Brief summary of five threshold concepts with key citations noted that establish it as a core concept in sustainability science, and examples of classroom exercises to help students move from one paradigm to another. Materials for select activities available at conservationofchange.org/teaching-resources unless otherwise noted.

complexity can also be troublesome because it contradicts the historical, Judeo-Christian assumption that humans are fundamentally separate from the rest of nature.

Collaborative institutions

Institutions, generally, are the rules and systems that people develop to organize collective action and govern various aspects of society, including human interactions with the environment. Institutions are described in different ways by scholars of different disciplines, for example as formal and informal, bureaucratic and socially embedded, or weak and strong (Cleaver 2002; Ostrom 1990). In the context of sustainability, much recent work focuses on the power of collaborative institutions, where people work together to develop systems for interacting with the natural world rather than relying on top-down (adversarial) regulation by the state or by markets (Lubell 2003). Collaborative institutions as a threshold concept unseat perhaps the most central modernist assumption regarding humans and the environment: the Tragedy of the Commons (ToC) (Hardin 1968). The ToC thesis has underpinned modern thinking and policy on natural resource management for decades, despite being inherently racist and based on scant empirical evidence (Mildenberger 2019). At its core, the

ToC is rooted in the belief that humans are fundamentally flawed by nature—that we will act out of our own individual self interest unless compelled by governments to do so. However, social scientists have long shown that this understanding of human nature is inaccurate (Quinn 1991; Sahlins 1972, 2008; Bowles and Gintis 2011). Elinor Ostrom and others have likewise shown that the ToC is only one of many possible outcome of human–environment interactions, one that is driven not by failings of human nature but by a failure of our state-based institutions to achieve equity and security for all members of society (Ostrom 1990; Robbins 2012).

Despite several decades of research refuting the ToC as the de facto outcome, it has proved to be extremely durable, which highlights its status as a conceptual anchor for the mainstream neoliberal paradigm (Feeny et al. 1990). As a threshold concept, the notion of collaborative institutions is troublesome, because it, in effect, inverts the ToC. Rather than seeing the ToC as an inherent problem that needs to be solved through top-down governance, this body of work reveals the ToC to be a problem that top-down and market-based governance create when they fail to attend to equity and security (McCay and Jentoft 1998; Loring 2016). Recognizing the importance of collaborative institutions, which can be powerful and effective at the local level, is also troublesome because it undermines the basic premise of neoliberal state-based natural resource management (that resources must be enclosed by markets and policies), proposing instead that local, community-based approaches can be at least as effective at achieving outcomes that are environmentally sustainable and socially just (Acheson and Wilson 1996; Berkes 2007).

Multiple ways of knowing

Research on environmental problems, in particular with Indigenous peoples and other local environmental experts, has revealed numerous fundamental inadequacies to the strictly positivist, natural science approach to understanding the world (Nader 1996; Cajete 1999). Indigenous and other local ways of knowing, which draw on experience gained firsthand while working and living with the land (Berkes 2008; Thornton and Scheer 2012), as well as knowledge obtained or revealed through training, story, dreams, and communication with nonhuman agents (Castellano 2000; Barrett 2013), are also valid and important ways of knowing that can contribute to efforts to improve sustainability research and practice (Wilkinson et al. 2007; Barrett 2013; Latulippe and Klenk 2020). Many practical examples have been documented where outcomes, both environmental and societal, have been improved through collaborations that empower local experts to bring their expertise into the decision-making process (Huntington 2000; Dale and Armitage 2011; Beaudreau and Levin 2014).

Not surprisingly, the increased emphasis on multiple ways of knowing in sustainability science and practice has proved to be particularly troublesome; some have called local and traditional knowledge a threat to effective management, while others have crafted extensive rationales for excluding or diminishing the legitimacy of local knowledge and stewardship (e.g., Howard and Widdowson 1997; Smith and Wishnie 2000; Wohling 2009). Making space for the validity of multiple ways of knowing can be especially challenging for someone new to the idea because the positivist philosophy of knowledge that is so extensively taught in western society teaches is that the scientific method is not just a powerful way of knowing but the only legitimate way of knowing (Moon and Blackman 2014).

To accept multiple ways of knowing, one has to move from a strictly positivist philosophy of knowledge to transdisciplinarity, which rejects binary, right-or-wrong propositions about the nature of the world and instead proposes the existence of multiple levels of reality, each knowable only through a different knowledge system (Nicolescu 2008). Importantly in cases where one way of knowing seems to conflict another are not thought of as contradictions but discontinuities: aspects of reality which neither knowledge system can fully account. This is an important aspect of how embracing multiple

ways of knowing is disruptive to the existing paradigm: because knowledge can never be fully translated from one way of knowing to another, the power normally associated with expertise is dislodged from single authority-holders and placed instead in the hands of a plurality of knowers who must work together to build understanding and determine actions.

No panaceas

Just as the positivist philosophy of knowledge posits a single, standardized way of knowing, the industrial paradigm emphasizes standardization and uniformity as superlative parameters for problem solving (Ackoff 1979). That is, the industrial paradigm asserts that the best solutions to a problem are always the ones that can be mass produced and deployed around the world, ideally, under some centralized system for command and control. Many technologies for agriculture and energy generation, for example, are designed to support highly standardized and centralized systems. By comparison, many of the alternatives that people are now pursuing under the banner of sustainability, whether for managing food, water, or energy, emphasize diversity rather than standardization and are designed to be distributed in nature and tailored to fit with local social and environmental complexity (Altieri 1995; Pahl-Wostl et al. 2012; Boucher 2016). As such, these initiatives are often heavily critiqued by industrial and neoliberal thinkers for lacking broad applicability and scalability (Asafu-Adjaye et al. 2015; e.g., Collier 2008)—in other words, for not being panaceas.

The sustainability paradigm fundamentally rejects the notion of panaceas (Ostrom et al. 2007), in large part as a consequence of recognizing complexity. Complexity highlights the messiness of the problems we face (Rittel and Webber 1973, Ackoff 1979), how the unique features of local contexts make one-size-fits-all solutions both ineffective and likely to generate unintended consequences (Kottak 1990; Degnbol and McCay 2007). Complexity also directs our attention to shared, root causes of problems like climate change, hunger, malnutrition, and population growth (Swinburn et al. 2019), forcing us to reckon with place-based societal change rather than simply pursuing technological fixes. Finally, rejecting panaceas is troublesome to existing power structures in society because it undermines any assumed justification for pursuing large-scale solutions that can be centrally owned and controlled, whether by industry or government (e.g., Boucher 2016).

Adaptability

The fifth threshold concept, adaptability captures the extent to which people and communities have the resources, networks, knowledge, and willingness necessary to accommodate and respond to environmental variability and change (Thornton and Manasfi 2010). This often involves livelihood strategies that embrace diversity; for example, traditional subsistence portfolios among Indigenous peoples often reflect seasonal patterns of variation in fish and game and provide numerous options should specific fish or game species be sparse (Hoogenraad and Robertson 1997; Brinkman et al. 2007). As noted above, modern, industrial systems of production seek to achieve uniformity and standardization, but simple and uniform systems, whether agroecosystems or grasslands or social networks, are generally less productive and less resilient than are more diversified and flexible systems (Tilman et al. 2001; Fraser et al. 2005; Carvalheiro et al. 2011; Baggio et al. 2016; Grêt-Regamey et al. 2019). Adaptability, thus, captures the imperative of embracing diversity and flexibility as a strategy for achieving sustainable outcomes.

At its core, adaptability involves the recognition that stability in nature is a matter of scale, the product of cycles of change at smaller and (or) larger scales (Gunderson and Holling 2002). By recognizing the ubiquity and necessity of change, adaptability captures the reality that working against change by trying to turn natural ecosystems into factory-like systems of production is the principle cause of environmental degradation. Enacting strategies that are adaptable involves being willing to change and

learn, both to accommodate natural variation in the world around us but also in the face of dramatic changes and disasters (Cinner et al. 2018). Adaptability is troublesome because it confronts the notion that with sufficient technology and expertise, humans can fully control the natural world and shape it to meet our whims and needs. Instead, adaptability requires that we reframe our expectations for what the world can provide, and be flexible enough to accommodate natural variability. It shifts our entire understanding of what sustainability entails: from a simplistic understanding of sustainability as stability, to a more complex understanding where sustainability means harnessing change to maintain a sense of our identity and key values while exploring and pursuing new collective visions for the future (Cumming and Collier 2005; Loring 2007).

Discussion

Understanding threshold concepts in general, and these five specifically, advances sustainability education and practice in multiple ways: first, it helps us frame the key aspects of the paradigm that make sustainability so transformative, whether for individuals in the classroom or for those working to implement sustainability in their livelihoods and communities. As a fundamentally new way of seeing the world, sustainability unseats common myths about humanity, specifically about our exceptional nature (that we are separate from nature) and our fundamentally flawed character (the ToC), both of which are rooted in Judeo-Christian philosophy and central to the rationale of neoliberalism. Sustainability also disrupts existing power structures, because acknowledging multiple ways of knowing and the power of institutions destabilizes the assumed mandate for state- and market-based controls over human behavior. This, in turn, opens the door to new, decentralized forms of collaboration and governance. And, finally, recognizing complexity and the failure of panacea thinking undermines the industrial logic of production, replacing standardization and efficiencies of scale with mandates for diversity, pluralism, and place-based solutions.

Next, threshold concepts help us to understand the long line of challenges, critiques, and abuses that sustainability has endured over the last several decades. Threshold concepts, when first encountered, can seem either naïve or cogently seductive. This has been the constant critique of sustainability; to those fully invested in the neoliberal paradigm of growth-based development and wealth creation, sustainability seems parochial at best. Yet, to those people who are legitimately disheartened by the problems facing modern society, and who feel disquiet with their current way of thinking, sustainability is incredibly attractive. If we accept sustainability as not just a repackaging of modernity but as a fundamentally new world view, it is imperative that we learn more about these key threshold concepts and the various challenges that people face when they encounter them.

For example, because threshold concepts are troublesome and transformative, it is not uncommon that some newcomers will try to coopt them by learning to mimic, or perform, the new paradigm, even though they never themselves fully buy-in. We see this regularly in greenwashing and other half-hearted performances of sustainability—where the concept is wielded only for its discursive, political, or economic benefits. The eco-modernist agenda is one such example of sustainability performance (Asafu-Adjaye et al. 2015), where the language used is evocative of paradigmatic change, but the actual prescriptions are simply accelerations of business as usual (Grunwald 2018).

Education for sustainability is widely understood as requiring a broad rethinking of the civic purposes of education around relations and transformation of the entire human enterprise, engaging with body, mind, spirit, emotion, and will (Sterling 2004; Lange 2018). To date, much sustainability education has been limited by its narrow and prescriptive scope, often emphasizing science and technology framings while failing to provide students a broad and transformed basis for critical thinking, autonomy, and creativity (Jickling 1992; Jickling and Wals 2008; Shava 2013). Threshold concepts, and the emerging associated literature, offer educators important tools and insights to reimagine

how they teach students to think within the sustainability paradigm (Sandri 2013). Academics looking to more effectively bring into their classrooms sustainability threshold concepts like those discussed here would do well to foray into these rich literatures on ESE and transformative learning for guidance on how to reimagine their pedagogies.

For example, learning threshold concepts is a multi-stage process, wherein the learner's way of seeing the world is transformed (Harmin et al. 2017). First, the learner needs to be brought to recognize the boundaries of their current way of thinking that make the new threshold concepts seem heterodox. During this process, the learner can experience psychological unease—as if they have had part of their identity stripped away. They recognize the problem with their current way of thinking, but do not yet have a new way of thinking with which to replace it. This is known as the "liminal space," a characterization drawn from anthropological research on ritual rites of passage (Van Gennep 1908). While liminal, learners can be vulnerable to the influence of cognitive biases such as confirmation bias and identity protective reasoning (Kahan et al. 2011), which can lead them to retreat from or even revolt against the new way of thinking. In **Table 1**, I detail activities for each of the five threshold concepts above that I have found to be helpful for bringing people through this liminal space. In general, this involves an iterative process with activities that enable students to re-examine familiar knowledge and experiences with the concepts offered by the new paradigm, so that they seem empowering rather than foreign and threatening.

In addition to the five threshold concepts introduced above, there are likely multiple additional concepts that are relevant to the sustainability paradigm that I do not explore in depth here. These include: no unitary command, which is the notion that effective leadership happens via teams rather than individuals (Pearce and Manz 2005); growth transitions, which describes the imperative of moving from quantitative growth (growth in wealth, size) to qualitative growth (growth in wellness, happiness) (Daly 1973; Odum 1998); shared destinies, which holds that humans and ecosystems can thrive together in win–win scenarios (Rosenzweig 2003; Loring et al. 2016); and nonhuman sentience and agency, which acknowledges that nonhuman biological forms, and perhaps even non-biological forms, are capable to thought, action, and communication (Cajete 1999; Harmin et al. 2017).

My intent here is not to suggest that there exists some master list of threshold concepts that collectively constitute the sustainability paradigm. Indeed, if one accepts the value of multiple ways of knowing and rejects panaceas, it makes sense to expect that there is no single sustainability paradigm, and that as such, some practitioners will come to embrace some of these threshold concepts but not others. As others have noted, a strength of the sustainability paradigm is its plurality (Kates et al. 2005), and this is a critical point of departure for sustainability from industrial and neoliberal paradigms. That being said, the threshold concepts noted above illustrate how they can be linked and mutually reinforcing, creating a series of progressive gateways into transformative sustainability thinking: complexity, for example, underpins the importance adaptation and helps us to recognize the problem with panaceas. It may be that, through further research, we find that threshold concepts in the sustainability paradigm need to be learned in a particular order (as in **Fig. 1**), with a few key tenets like complexity underpinning a fulsome understanding of other, more secondary concepts, such as adaptation. What's more, and given that the sustainability paradigm is only a handful of decades old, there may be additional important concepts that we have not yet come to recognize or fully understand.

Ultimately, we learn many of the unsustainable vestiges of modern, industrial thinking not from classrooms but in everyday life—from books, movies, and life experiences. If sustainability is indeed to be a shared societal goal, it is essential that education at multiple levels seek to provide transformative experiences that introduce learners to these core tenets of sustainability, so that future generations

of people can grow up as native sustainability thinkers, rather than as newcomers struggling in their college years or later to shed stubborn assumptions and biases.

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Author contributions

PAL conceived and designed the study. PAL performed the experiments/collected the data. PAL analyzed and interpreted the data. PAL contributed resources. PAL drafted or revised the manuscript.

Competing interests

The author has declared that no competing interests exist.

Data availability statement

All relevant data are within the paper.

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