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Sustainability Science Engagement and Engaged Sustainability Science

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Commentary

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The *South African Journal of Science* is committed to multidisciplinarity as part of our mission, and we are interested in publishing on issues of broad local and continental concern. However, working, thinking and debating across disciplines is often easier said than done.

For this reason, we were delighted to receive an approach for a special issue showcasing the achievements and challenges of a Community of Practice (CoP) and its work in action – the outcome of which is the current special issue on 'Sustainability Science Engagement and Engaged Sustainability Science'. Because the Guest Editors are part of the CoP, our editorial process with this special issue had to pay special attention to questions of independence of review processes. As members of a CoP may have a vested interest in the outcome of reviews of submissions from that same group, review processes were undertaken by our usual editorial team, none of whom is affiliated with the CoP. We did ask the Guest Editors for suggestions of reviewers and expert readers, but we did not necessarily follow their suggestions – we considered these as we would consider suggestions from authors themselves.

We are very pleased, therefore, not only to be publishing a special issue on very important issues for science in our context, but also that, with the kind cooperation of the Guest Editors, we are able confidently to state that all papers in the special issue (and those that were not accepted) were subject to the same levels of rigorous assessment as all other submissions to our Journal.

We thank the Guest Editors, Prof. Heila Lotz-Sisitka, Prof. Janice Limson and Prof. Lesley le Grange, for convening and guest editing this special issue, and I thank the Associate Editors and our in-house team (Phumlani Mncwango, Nadia Grobler and Dr Linda Fick) for their sterling work on this issue and for doing this work with such cheer and collegiality.

Leslie Swartz, Editor-in-Chief

About the issue

This special issue on 'Sustainability Science Engagement and Engaged Sustainability Science' juxtaposes science engagement with engaged science. The contributions, with their diversity of perspectives, help to more substantively elaborate the full meaning of transformative science for and with society, including in and through educational interventions that can advance engaged science and science engagement.
(Cover design: Nadia Grobler)

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Sustainability science engagement and engaged sustainability science

Introduction

The South African *Science, Technology and Innovation Decadal Plan* (2022–2032)[1] shows a strong commitment to *science engagement*, with most references referring to the communication of science. This plan builds on the 2015 Department of Science and Innovation (DSI)'s *Engaged Science Strategy*[2], which notes that engaged science approaches are as yet underdeveloped in South Africa. The Decadal Plan[1] explicitly relates science engagement to the need for more inter- and transdisciplinary approaches to science, with mention of greater inclusion of stakeholders in defining the needs and objectives for research, but without clear insight into how this is to be done or supported. More in-depth approaches and understanding may be needed to adequately bridge the science-society gap, including in and through the educational sphere. This special issue of the *South African Journal of Science* addresses this through joining the DSI conversation on science engagement[1,2], by juxtaposing science engagement with engaged science.

Science engagement typically draws attention to public engagement with science[2], and may easily be misunderstood as a simple activity of communicating scientific findings to publics once the scientific process is complete. This is most visible in the dominance of the concepts of 'science communication' and 'dissemination' in the science arena. However, as can be seen from the discourse in the Decadal Plan[1], and across contributions and deliberations in this special issue, *science engagement* takes different forms, reaching far beyond one-way communication approaches between scientists and publics, and encompassing a range of concepts such as inter- and transdisciplinary science, knowledge co-production, place-based research and learning, citizen science and responsible research and innovation, amongst others. These concepts bring processes of *engaged science* into focus, and raise questions on how the sciences are promoting active involvement of publics in scientific knowledge (co)production, how this may influence science, communication, action and practices, and, in the process, challenge and reframe narrow views of science engagement. This conversation is not insignificant given calls to decolonise scientific practice in South Africa, to re-think human-nature relations in and through research, and to demonstrate a more visible impact of research in policy and practice arenas. Through such a conversation, we may potentially also contribute to rethinking, or at least broadening, the notion of science impact itself.

Viewed in relation to the complex, wicked problems[3] that are typically dealt with by the sustainability sciences (e.g. climate change, water insecurity, landscape change and governance), Grove and Pickett[4(p.7)] argue that inter- and transdisciplinary sciences require more durable science platforms that can address the spatial-temporal and ethical challenges of the social-ecological crisis, which simultaneously manifest as "immediate crises and emergencies over days and weeks; to sudden events over months and years; to extensive, pervasive, and subtle changes occurring over decades" at different levels and scales of society with differing impacts. However, we do not only need more durable science platforms. The process of scientific knowledge production itself needs to be revised in relation to affected publics and the more-than-human world, challenging the often taken-for-granted established role of higher education and research in society. This is beautifully pointed out in the book review by Du Preez, which opens the special issue.

Contributions in this issue draw on a range of disciplines and publics generating co-engaged knowledge that advances understanding of *'Sustainability science engagement* and *engaged sustainability science'*, with emphasis on the relationship between these. In particular, the research articles in this special issue bring together selected contributions from a National Research Foundation (NRF) / Department of Science and Innovation (DSI) Community of Practice (CoP) involving 11 Research Chairs working in the sustainability sciences in and across natural and social science disciplines. The core interest of the CoP was to develop theory and practice at the interface of sustainability science, policy and practice. Each Chair worked with a network of partners (academia, state, civil society, private sector), with other chairs, and with a vibrant network of early career researchers, the configurations of which are reflected in the co-authorships in the special issue. The issue also includes invited commentaries and book reviews which complement and expand the focus and content of the special issue. As such, the special issue joins the broader conversation emerging in the South African science community on science engagement introduced above.

Wicked sustainability problems, engaged science and science engagement

All the contributions (articles, commentaries and book reviews) in this special issue demonstrate that the sustainability sciences are embracing the in-between space that exists between the concepts of 'science engagement' and 'engaged science', thereby clarifying both. The research papers show that sustainability scientists from a variety of disciplines are explicitly engaged with development of citizen sciences, and inter- and transdisciplinary approaches to knowledge (co)production, as they engage the complexity of 'wicked problems'[3] that characterise human-environment crises, such as climate change, water insecurity and pollution, landscape change and biodiversity loss, or the condition of 'hot messes' referred to by McGarry et al. As said by McGarry et al. and Du Preez, these can be traced back to the privileged irresponsibility that contributed to coloniality and ecological damage.

In response, papers by Mickelsson et al., Odume et al. and Nqowana et al. consider the potential of citizen engagement in addressing the ubiquitous challenges of water pollution and quality in South Africa. The paper by Nqowana et al. and the commentary by Graham et al. argue that citizen science tool innovations, if socially

conceptualised in collaboration with communities, and if combined with transformative learning approaches, can expand capabilities for engaged science and more inclusive water governance. Odume et al. argue for giving attention to competing interests and motives in such initiatives. Providing a wider perspective on this, Mickelsson et al. say that, "Life in river systems is increasingly dependent on human actions that bring river health into being", pointing out that citizen science, practised as engaged sustainability science, *is* a form of sustainability practice that can heal damaged human-environment relations.

With a wider landscape lens on engaged science, the paper by Shackleton et al. focuses on landscape and catchment management. It reports on development of approaches to collaborative management in complex catchments, while the paper by Ivey et al. focuses on collaboration in bioremediation of invasive plants in complex landscapes. The authors of both papers argue for giving detailed attention to how communities of practice are formed and how they work together in landscapes, offering guidance to researchers seeking to engage in similar forms of collaboration. The commentaries by Palmer and Tanner, and Kuse et al. add impetus to their arguments for investing time and resources in transformative social learning and adaptive systemic approaches for advancing both science engagement and engaged science in catchments and landscapes. The paper by Rosenberg et al., located in a biosphere reserve context, argues that explicit evaluative reflections on such processes can ensure that transformative concepts translate into transformative practices.

As shown in these contributions, dealing with 'wicked problems' in the contexts of pollution, degradation and sustainability landscapes in co-engaged ways, demands new methods for scientific practice and science engagement. All of the papers in the issue show that more complex configurations of participatory methods are emerging as scientists seek to engage societal actors in the investigation and resolution of complex problems. The papers show that the development of methods such as forming transdisciplinary communities of practice (Shackleton et al., Ivey et al., Mickelsson et al.), place-based transgressive learning as open-ended inquiry (Lotz-Sisitka et al.), co-defining theories of change (Rosenberg et al.), emic ways of approaching complex systems analysis (Mbatha), adaptive systemic approaches to catchment management (Palmer et al.), and place-based co-management and livelihoods co-construction (Kuse et al., Mubangizi), are offering some ways forward for engaging such wicked problems through inter- and transdisciplinary science practised as engaged science.[5] In their commentary, Van Breda and Treffry-Goatley talk of 'methodological agility' which "helps researchers to switch between disciplinary approaches, avoid instrumentalism, and address the 'legitimation crisis'... – the erosion of confidence in scientific processes". They argue that such 'methodological agility' is "crucial in building legitimacy through co-constructing just and sustainable pathways" – a point emphasised also in the book review by Vogel, who reflects on methodological approaches that are 'quantum informed' in the sense that they require "beliefs, relationships, metaphors, entanglement consciousness and agency". The book review of *Agency and Transformation* by Hammond draws attention to the detailed research being undertaken internationally to both conceptualise and analyse the emergence of transformative agency, while the book review by Ncube draws attention to wider global justice concerns and the politics of achieving climate justice. The care taken to elaborate these methods, and their theoretical and practical dimensions in this special issue, helps to further develop the academic, political and contextual rigour associated with science engagement and engaged science.

Conceptual, philosophical and contextual dynamics

Contributions in this special issue address the relationship between inter- and transdisciplinary research and potentially transformative science and education, which at present is under-developed as science engagement and engaged science praxis. Pennington et al.[6(p.564)] note that,

> *... potentially transformative research depends on the existence of an interesting and worthwhile problem to which participants can contribute in salient ways, human and material foundations within disciplines, collaborative mutualism across disciplines, and a transformative learning process that enables knowledge integration across diverse perspectives.*

As such, the papers in the special issue bring *relational approaches* into focus as a philosophical dynamic of sustainability science engagement and engaged sustainability science. Not only are new methods needed, but there is a need to engage with conceptual, philosophical and contextual dynamics, particularly a shift from dualism between 'objectivity' and 'subjectivity' towards intersubjective and interspecies relations.

All the papers focus on human-environment relations as a foundational premise of sustainability sciences, but there are some nuances associated with these relations. The paper by Mickelsson et al. and the Nqowana et al. paper show clearly that microorganisms in rainwater tanks and rivers affect the health and well-being of communities and other life forms – a relationship that can be detected through citizen science technology innovations. Both papers give attention to the microbial world and its relations to the human world – not as separate entities, but as interrelated. The book review by Du Preez and commentary by McGarry et al. take this line of thinking further to embrace the post-human concept of human-environment relational assemblages.[7] McGarry et al. provocatively point to the need for new "organs of perception" if we are to fully embrace interspecies relations and reduce the dominance of humans as the central figure in sustainability science.

The papers by Shackleton et al. and Ivey et al. both point to the work needed to establish collaborative relations in dealing with complex sustainability concerns in landscapes, with emphasis on the formation of communities of practice constituted by multi-actor groups, not all of whom share the same experience or background. Odume et al. point out that, in the context of the Upper Vaal catchment, water regulation and management has become a contested space between resource users and regulators. Odume et al.'s research points to scientific credibility in the methods for deriving water quality standards as an important mediator of such contestation, along with the need to build trust within the regulatory system. In the place-based learning contexts referred to in the Lotz-Sisitka et al. paper, which gives credence to local and Indigenous knowledge practices, people's cultural histories and regenerative place-based relations, and epistemic justice were found to be equally important to sustainability transformations. Mbatha's commentary points to finding new language and metaphors for perceiving relationality in African human-environment contexts – a point also made by Mubangizi in her argument for place-based approaches to engaged science. McGarry et al. point to a radical transformation of metaphors and frames of reference, charting instead a slow relational ecology of science praxis.

An emphasis on learning, education and skills development

As can be seen from the above, in the NRF/DSI CoP, researchers focused on three complex or 'wicked' problems in South Africa, broadly framed as clean water, climate action, and landscape management and governance. Additionally, we sought to develop an understanding of transdisciplinary science approaches which includes an explicit focus on decolonial, place-based approaches to developing transdisciplinary science in South Africa. To cement the longevity impact of such innovations, the importance of *learning* and *education system* transformations surfaced.

The relationship between engaged science, learning and sustainability is highlighted in all the papers in this special issue, but is substantively engaged in the papers by Olvitt et al., Shackleton et al., Lotz-Sisitka et al., and Rosenberg et al. As indicated above, this requires conceptualising and advancing forms of engaged science that can be co-developed by and with a diversity of publics, and that advance mutual learning, as evidenced by Nqowana et al.

A focus on learning itself would have limited value in the longer term, if not conceptualised and practised as education system transformations that can strengthen science engagement and engaged science in sustainability transitions. Education system practices can be catalytic of

wider forms of learning for sustainability if also transformed.[8] Papers by Olvitt et al., Ramsarup et al., and Rosenberg et al. all explicitly discuss changes necessary in curriculum and skills system development to strengthen sustainability science engagement in practice. Olvitt et al. articulate principles guiding transdisciplinary curriculum design, while Ramsarup et al. indicate that dominant market-led logics of supply and demand are contradictory in framing skills research for just transitioning to sustainability. Additionally, the book review by Mandikonza urges scientists to give careful attention to ways of engaging with teachers on sustainability concerns that can advance transformative learning and pedagogy in the schooling sector.

Institutional support and development

A final thread running across the papers in the special issue is a call for stronger institutional support for transdisciplinary science advancement, engaged science and science engagement. Such support is needed, not only for funding the co-engaged forms of inter- and transdisciplinary science presented in the special issue, but also for the education, training and research practice shifts that are needed.

In this special issue, Hackmann and Van Jaarsveld comment on efforts to create a more sustainable funding landscape for transdisciplinary sciences, while Rosenberg et al. draw attention to the evaluation of science engagement interventions as learning processes, and Van Breda and Treffry-Goatley and McGarry et al., amongst others, comment on the ethics of research. While transdisciplinary sciences are making progress with advancing the intensity of practitioner involvement in science, they may fall short in realising empowerment – a point addressed in the papers by Shackleton et al., Nqowana et al. and Lotz-Sisitka et al., amongst others. Furthermore, researchers in this special issue draw attention to the shifts in institutional approaches needed to embrace decolonial, place-based approaches that fully engage local epistemologies, languages and ontologies, calling for a deeper commitment to the ontological and epistemological foundations of transdisciplinary forms of engaged science (e.g. Lotz-Sisitka et al., Mbatha, Mubangizi, McGarry et al., Van Breda and Treffry-Goatley, Vogel). Those working in education draw attention to institutional support required for curriculum and skills system innovation – an issue addressed in the contributions by Rosenberg et al., Ramsarup et al., Olvitt et al., Allais and Mandikonza.

Overall, the special issue shows that the role of transdisciplinary and decolonial sciences, transformative learning approaches, and sustainability transitioning through engaged science needs improved articulation in relation to calls for university education and the education system more broadly to better serve the public and common good. However, as said by Allais in her commentary, the education system cannot make the transition on its own. For this, wider policy, societal, and economic transformations are needed, as also pointed out in the book reviews by Du Preez and Ncube.

Conclusion

As shown across the papers, commentaries and book reviews, this special issue gives attention to science engagement and engaged science processes and their clarification, and also to the specific methods and methodological, conceptual and contextual premises necessary to advance sustainability science and society relations.

The special issue demonstrates a growing experience among South African sustainability scientists and practitioners of science engagement and engaged science approaches. It surfaces temporality questions related to the tensions experienced around short-term projects and an expressed need for longer-term, more durable science platforms for sustainability sciences to address diverse types of complex, wicked problems. It also surfaces spatial questions in relation to place-based concerns, and bounded landscape-level relational science engagements. It furthermore deepens methodological, epistemological and ontological deliberations on science engagement and engaged science.

Overall, the special issue contributions, with their diversity of perspectives, help to more substantively elaborate the full meaning of 'transformative science for and with society', including in and through educational interventions that can advance engaged science, and science engagement.

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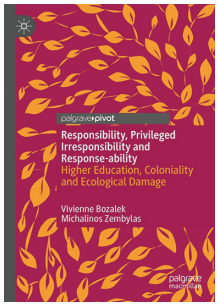
BOOK TITLE:
Responsibility, privileged irresponsibility and response-ability: Higher education, coloniality and ecological damage



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Difficult times … exciting times!

Joan Tronto, in the Foreward to *Responsibility, Privileged Irresponsibility and Response-ability: Higher Education, Coloniality and Ecological Damage*, opens with the following line: "These are difficult times in higher education; there are difficult times everywhere." In this book, Bozalek and Zembylas live up to their usual high standard of engaging with the complex questions of our time, by skilfully balancing "the creative potential of critical thought with the dose of negative criticism and oppositional consciousness that such a stance necessarily entails"[1].

Bozalek and Zembylas' intellectual project traces coloniality and ecological damage as it relates to higher education, and, in so doing, they do what Donna Haraway[2] suggests: they stay with the trouble (of higher education), and through the trouble, they invigorate productive, alternative lines of flight that can help us to navigate ourselves in rapidly changing higher education spaces. Put differently, they work through problems of humanism which are, by implication, problems and difficulties of our times. In their commitment to 'stay with' and 'work with and through' these difficult times, Bozalek and Zembylas make a unique contribution to Critical University Studies through introducing posthumanism and new feminist materialism (one strand of thinking in posthumanism) to the debate. Posthumanism opens exciting possibilities for us to think about. It is not anti/against humanism, nor does it imply something post/after humanism. Posthumanism suggests staying with the troubles and difficulties of our time and challenging the centrality of (the) human/ism. It entails a sensitisation toward the multiple realities of our times (which includes the dominance of humanist thinking that has led to unprecedented ecological disasters) and seeks critical and creative alternatives to difficult times.

For Bozalek and Zembylas, difficult times in higher education are marked by several interrelated global challenges. The COVID pandemic has disrupted normal processes, ecological degradation continues rapidly, violence is scaling at exponential rates, and there is increasing demand for justice. In higher education, these global challenges manifest as disruptions to the traditional notion that academic inquiry exists in a separate, purified realm. Economic pressures force universities to prioritise fields of study that are instrumentally useful, leading to a decline in the collective academic life and increasing inequality within institutions. Academics face challenges from both political extremes, with criticisms of being too left-leaning or 'woke', combined with the slow progress of institutional change prompting anger from students. Bozalek and Zembylas argue that these issues indicate a loss of faith in the ability of higher education to respond to problems, especially when employing traditional ways of thinking.

In tracing a new line of flight for Critical University Studies, and suggesting alternatives by thinking-with theorists (such as Karen Barad, Vinciane Despret, Deborah Bird Rose, Donna Haraway, Maria Puig de la Bellacasa, Anna Tsing, Iris Marion Young, Joan Tronto and Margaret Urban Walker) who have written about responsibility, privileged irresponsibility and response-ability, Bozalek and Zembylas not only illustrate how higher education can be conceptualised in current conditions, but also how it might be done differently and reconfigured in more generative and transformative ways. They justify their intellectual project as "timely because the current conditions of the world – coloniality, capitalism and neoliberalism, social injustice and the ecological crisis – have dire implications for higher education and its future. Responsibility, privileged irresponsibility and response-ability are all concerned with ethical, ontological, epistemological and political understandings and implications for our world; therefore, the combined use of these concepts will shed new light on these implications for higher education." (p.2)

To develop their intellectual project, they dedicate the first part of the book to chapters that separately deal with the concepts of responsibility, privileged irresponsibility (including complicity and non-innocence) and response-ability or responsiveness, drawing on the entanglement of posthuman/feminist new materialism and political ethics of care. The integration of feminist new materialism, posthumanism, and political ethics of care offers alternative perspectives to these concepts; privileging relational and material engagements over abstract, individualistic notions of ethics and agency. In the second part of the book, they turn their focus to higher education and how privileged irresponsibility has given rise to and exacerbated such world conditions as coloniality and ecological damage. "More explicitly," as they explain, "the second part of the book considers how privileged irresponsibility has been important in producing coloniality and ecological damage. It also explores what can be done about this state of affairs, in terms of assuming responsibility (in the form of acknowledgement of complicity and non-innocence) as well as the ability to respond (response-ability) (being able to respond and allowing for responsiveness) to the conditions of colonialism and the damaged planet." (p.5)

Bozalek and Zembylas explain that our ability to respond (response-ability) always happens in intra-action (nothing predetermined precedes our ability to respond) and that being able to respond or allowing for responsiveness is always an ethical matter. Against this backdrop, the book emphasises the importance of ongoing ethical engagement in higher education. This means continually questioning and reconfiguring academic practices and policies as a form of enacting our ability to respond. Universities should be spaces for critical questioning and complicated conversations, encouraging students and staff to engage with complex ethical issues and injustices. This requires dis-identifying with the mechanistic worldview and practices inherited from colonial modernity and racialised capitalism.

In conclusion, *Responsibility, Privileged Irresponsibility and Response-ability* offers a comprehensive and critical tracing of the role of higher education in addressing colonial and ecological challenges and suggests that higher education spaces embrace relational and decolonial ethics for more just and sustainable futures. The book invites us to think otherwise, in a radically open manner, to enact our ability to respond, and be responsive, in the difficult times that higher education faces. The immanent potential of such a radically open approach is ripe with possibilities. Difficult times, yes… But, exciting times!

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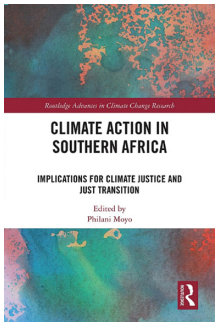

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Climate action justice in an unequal and unjust world

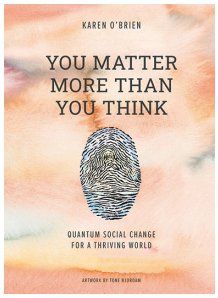
It is tempting for academics to jump on the bandwagon of globally topical and discursive development themes and rush to publish articles, chapters or books that lack analytical and empirical quality and are delinked from the world of decision and policymaking. Notwithstanding the dominant voice of the editor in 6 of 13 chapters, Philani navigates this temptation by assembling diverse and seasoned researchers and development practitioners whose multidisciplinary approach to interrogating the pertinent global policy issue on how to address climate change in ways that do not accentuate extant inequalities in the Global South, within and between communities, is insightful and timely. The book *Climate Action in Southern Africa* amplifies the voice of the Global South in the international discursive policy spaces on climate justice action, making it relevant for researchers, students, climate change activists, governments and financial actors.

The book acknowledges that the impacts of climate change are already acutely being felt across the southern African region, evidenced by the frequency of droughts, floods, and excessive temperatures among many extreme climate change induced weather phenomena. This has negatively affected the largely agro-based economies and livelihoods of vulnerable communities across the region. Smallholder farmers' agency and choices are limited and constrained in rural communities, which has negatively impacted their capacity to manage their rangeland carrying capacities for their livestock and to use resilient food production systems that guarantee food security. Climate change is negatively impacting water demand management practices in metropolitan urban centres. Poverty, inequality and job losses are being accentuated by climate change, putting the future of the youthful populations at great risk. Climate change induced mobility heightens gendered inequalities and compounds social cohesion in the region and communities. Across the region, several efforts to address climate change through strategies such as climate-smart agriculture, promotion of renewable energy use, and ecosystem renewal through reforestation projects have yielded differentiated outcomes. This is a problem caused as much by weak legal, policy and institutional frameworks and weak climate financing mechanisms by governments, as they are driven by the challenges to integrate climate justice and just transition considerations into climate action at global, national and community levels.

The chapters in this book collectively address the politics of achieving climate action justice in an unequal and unjust world. There is spirited resistance to the idea of 'historical responsibility' and 'climate debt' by some actors in the Global North. Philani and colleagues strongly push back and absolutely "… disagree with the argument … that climate justice is merely about individual and collective climate action that simply takes account of different vulnerabilities, resources and capabilities without delegating primary responsibility for those actions" (p.5). This is a legitimate demand from the margins, at global, country and community levels. The severe impacts of climate change in the Global South are barely proportionate to historical and present responsibilities related to greenhouse gas emissions. In the Global South, the carbon-intensive sectors are a double-edged sword: they are major contributors to greenhouse gas emissions and equally significant drivers for economic, industrial and social pathway transformations for southern Africa.

Drawing insights from a multipronged theoretical lens – inclusive of sustainable development, sustainable livelihoods, human rights, intersectionality and gender – the authors dexterously discuss the implications for climate justice and just energy transition for the southern African countries and their communities. First, they argue that, in order not to accentuate extant global inequalities and injustice, climate action justice necessitates that the Global North support and enhance the climate action resilience capacities of the Global South through just climate financing models and technology transfer. Second, just energy transition initiatives at country and community levels must be inclusive and participative to protect jobs, vulnerable communities and differentiated groups within the communities. The southern African governments' capacities and political will to foster collaborative climate justice action among key stakeholders, such as labour unions, civil society and the private sector, is crucial.

BOOK TITLE:
You matter more than you think: Quantum social change for a thriving world



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Making sense in a complex, messy world: Relationships, agency, fractals, paradigms and YOU

How do we live in a world buffeted by change in political, social, environmental and personal contexts? How do we continue to thrive and not lose hope in the dystopian times surrounding us? In her beautifully crafted book, supported with various artistic illustrations by Tone Bjordam, leading global change scholar and professor at the University of Oslo, Karen O'Brien, takes the reader on a journey of self-actualisation and self-reflexivity and collective agency in how to better navigate and live in a world of complex risks and challenges.

In this book *You Matter More than You Think,* O'Brien helps us to see where and how we as citizens and co-habitants on our soul journeys can co-operate and can make a difference in this world.

O'Brien uses quantum social change as a way to look deeper into what it means to be a human being and fellow sojourner on the planet. The book is a useful companion to Alexander Wendt's book *Quantum Mind and Social Science: Unifying Physical and Social Ontology*.[1]

Through the thought-provoking chapters, the reader is not only carefully helped to connect with themselves, but is also challenged to see how important it is to build a collective, agentic perspective to understand their role in the global challenges facing humanity. The focus on the importance of mattering; the role of beliefs and why these matter as we try and engage in the world; ways of thinking – paradigms; relationality and the role of relationships; the role of metaphors; entanglements and connections; consciousness; agency; and fractals are examined, ending with a special section on 'YOU'.

In the first chapter of the book, O'Brien argues that we can all do better than merely coping and or adapting to crisis upon crisis. Rather, she argues that:

> *To do better requires thinking differently, acting differently, and* being *different.* (p.2)

The questions raised are not, as she argues, as much about *whether* we can make change happen in transformative ways, but *how*? By inviting the reader to consider various dimensions and ways in which we can approach the challenges besetting the globe and humanity, she argues that collective change is made up of individual change. We are all, in some way, entangled through meaning, values and language and our sense of ourselves, and how we see ourselves and our relations with nature and society are underpinned by the nuances that quantum social sciences can offer. Using a quantum social sciences lens, we are not only separate but are also connected through relationships and communications – all critical for transformative social change.

Chapter 1 of the book provides a useful background to where and how we are all currently living – in a time of various crises that require actions (e.g. 'bending the curves' for greenhouse gas emissions in climate change and related contexts). The need to probe deeper and wider into why and how *'we'* and *'you'* matter in this complex world is clearly unpacked and supported with beautifully drawn illustrations of complex earth system 'science' components. The interactions of how worldviews of classical underpinnings and understandings of development can be different to, and have implications *for how* we act in the face of change are critiqued. Understandings of 'well-being' and the implications for how one engages in the scope and actions that can be undertaken for transformative change are also examined:

> *Again, this is not to deny the significance of the Enlightenment worldview, but it is essential to recognise its limitations and negative consequences for many people and much of the planet.* (p.14)

By exploring examples and explanations from quantum theory in Chapter 2, some of the paradigms and the ways we think are illustrated. These are explored together with deeper meanings of social change and the role that quantum computing and other advances in quantum physics and their links to social change can play.

In Chapters 3–9, some of the ways of thinking and how they can shape our actions for change in this complex world are unpacked in more detail – namely, beliefs, relationships, metaphors, entanglement consciousness and agency. The chapter on agency, for example, explores the "fragmented dualisms of our classical world; agency in a quantum world acknowledges that [I/we] are [whole/parts]" and focuses attention on the 'quality' of our agency as we show up in the world aiming for inputs and influencing change:

> *When these values are at the heart of individual agency, collective agency, and political agency, it is possible to generate new, fractal-like patterns that replicate across scales, in every moment.* (p.99)

> *…human and social fractals embed values that replicate at all scales.* (p.98)

Finally, in the last chapter of the book, we are brought back to the main set of reflections on why YOU matter in the issues that have surfaced and been explored in the book:

> *Quantum social change is not just about choosing a different paradigm. It is about* being *a different paradigm.* (p.122)

The book is made richer by the wonderful artistic contributions and the Epilogue which contains a list of questions that were raised in a series of preparatory engagements and webinars that were held as the book was written. A draft of the book manuscript was made available between June 2020 and March 2021 and was downloaded by over 800 people and inputs and questions were gathered from several other people. Thus even though COVID-19 presented a time of separateness for many, this collaborative approach has made the book even more engaging. The concluding sections for each chapter also contain reflections that prompt the reader to do a little more thinking on some key issues.

The value of the book is not only in that it highlights key questions and raises sometimes very complex quantum perspectives, but it also argues that we need to be thinking about *how* I/we can enable progressive change in our changing world. The book has an extensive resource of scholarly and popular references and materials and thus the book also serves as a solid reference book.

The only criticism, which is minor, is that it would have been good to have more examples informed from various perspectives (e.g. the Global South, the Global North) of what such 'being' and 'doing' can mean in contexts often fraught with competing and contested contexts, politics, cultural dimensions and notions of YOU.

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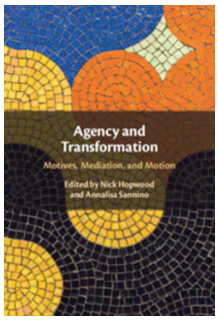
BOOK TITLE:
Agency and transformation: Motives, mediation, and motion



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Reviewing 'Agency and Transformation' from a South African perspective

The graphic cover of this publication superbly illustrates the multi-vocal clustered mosaic of contributions bound together by Cultural-Historical Activity Theory (CHAT). Academics and students applying CHAT principles would benefit from the contents, as would practitioners of organisational development, education and training professionals, and public servants entrusted with all aspects of socio-economic development. Crucially, the editors, Hopwood and Sannino, elucidate the urgency of transformative agency, where "… the givenness of the future is illusory".

Theoretical approach

CHAT offers an alternative to the qualitative stance of a neutral observer, in a theoretically grounded interventionist approach. The foundational concepts of Vygotsky[1] underpin the four generations of activity theory[2], inspiring the motifs of motives, mediation, and motion. Agency is not neutral, nor exclusively a facet of the individual, but conceived of as a dialectical inclusion of a socially and culturally situated individual capable of contributing to collective achievement.[3] Change Laboratory interventions, involving Vygotskian concepts of mediated activities and double stimulation, enable new learning and the development of transformative agency. Envisioning beyond social inequality, or the existential threat of climate change, evokes the philosophies of Gramsci and Freire[4], and post-colonialist African leaders, such as Nyerere[5].

Relevance to South Africa

The content resonates deeply with contemporary South African expectations. Envisioning enactment of utopias and a social justice agenda speaks to post-apartheid challenges of: land restitution and agricultural inclusion; provision of health and housing services; recognition of first nation languages, religions, histories, and cultures; and the decolonisation of school curricula, and provision of education and training.

South African studies provide an exemplar of developmental research. Land restitution and sustainable community development interventions in "agency from below"[6] address the legacies of colonialism and apartheid in seeking cognitive justice and the transgression of class structures. Similarly, in a Brazilian rural community consisting of farmers and workers from an agricultural association, the objectives of achieving environmental recovery and social inclusion by strengthening family farming resonate with the objectives of South Africa's recently formed Government of National Unity.

Directly comparable to South Africa, Brazilian health services are described as broadly differentiated between: younger, less educated, lower-income mothers in the public sector, with older women of higher income and education in the private sector. The variable quality of maternal care across Brazil produces a level of maternal mortality in excess of that expected in a middle-income country. Agentic promotion of women's rights increased empowerment in childbirth care.

The operationalised oppression within the health system is comparable to the education system described by first nation citizens, and to colonial empire education systems. The Finnish homelessness project includes resolution of societal imposition of stigma, significant in resolution of apartheid-era geographical demarcations in public housing. Identification of positive practices potentially encapsulated in isolated units is addressed in a bottom-up approach of frontline workers sharing successes. The approach of uniting transformative processes with supportive pedagogic instruments enables movement forward during periods of uncertainty – a process relevant to contemporary challenges.

On the youthful African continent, education and training are key to enabling agency and achieving a transformed post-colonial future. In India, a study of teacher discourse during teacher-sharing meetings demonstrates that agentic action is not a generic formula, identifying a complexity of institutional demands, relationships, and development of common knowledge. Similarly, the impact upon students of differing circumstances and policies is evidenced in a UK study of adolescents excluded from school following inappropriate behaviour, confirming how cultures and histories mediate individual development and institutions. Confirmation of socio-cultural influences, rather than interpersonal relations, is informative when considering nine provinces of vastly different histories and cultures.

Psychological and sociological static categorisations of youth future orientation are countered by non-profit volunteer work, civic engagement, and climate change activism. In China, analysis of children's story-telling narratives of their response to educational disruption during the COVID-19 pandemic shows that children's agency derives from contradictory motives, confirming Vygotskian perspectives on social crises/human development relationships. The encapsulation of traditional educational subjects into relatively short discrete blocks is also questioned. The proposal for an interventionist methodology focusing upon the generation of use value would potentially benefit South African curriculum developers – given persistently high levels of youth unemployment.

Conclusion

The editors have successfully collated global research – inclusive of the Global South and BRICS nations – and addressed content of direct relevance to the South African challenges of poverty, inequality, and unemployment. We carry with us our historically derived social positioning. Commencing from that positioning and the social circumstances of individuals, focuses upon cultural tools, thereby releasing the potential for new learning, the

creation of new cultural tools, and a better future – precisely the challenge of the newly created Government of National Unity.

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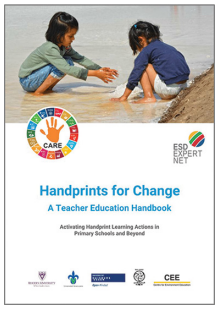
BOOK TITLE:
Handprints for change: A teacher education handbook – Activating handprint learning actions in primary schools and beyond



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Activating handprints, not footprints!

One of the key activities in sustainability science engagement is often work with teachers and schools. However, such work can fall into the trap of 'issues messaging' to teachers and children. A new international handbook, with the potential to guide sustainability science engagement with teachers and schools through education for sustainable development (ESD), offers excellent theoretically grounded and practical guidance for those wishing to develop sustainability science engagement programmes with teachers and schools. Entitled *Handprints for Change: A Teacher Education Handbook – Activating Handprint Learning Actions in Primary Schools and Beyond,* the 148-page book by Kartikeya V. Sarabhai (India), Christa Henze (Germany), Robert O´Donoghue (South Africa), Juan Carlos A. Sandoval-Rivera (Mexico), and Chong Shimray (India) has been developed to design rigorous and CARE-ful, ethics-led and situated-learning approaches for facilitating ESD in classrooms.

The book highlights the role of teachers as facilitators and mediators of learning who can nurture a love of self, others, and the environment within students, guided by an ethics of care. Teachers can achieve this through the concept of 'Handprint CARE' actions, which are ethics-driven learning activities that inspire learners to become changemakers for a more sustainable future. The metaphor 'handprint' challenges the dominance of the metaphor of 'footprints' in sustainability sciences, offering options for not only the teaching of issues and challenges related to sustainability concerns, but, importantly, ways of involving learners in contributing to sustainability action, and showing care for self, others and the environment. ESD, according to UNESCO[1], should support people of all ages to gain knowledge, skills, and values to address global challenges and live more sustainable lives.

Overall, the book contributes to the policy goal embraced by Sustainable Development Goal (SDG) #4, Target 4.7: "By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development."[2] This emphasises that education for sustainable development should be viewed as a key feature of educational quality. In a South African context, it brings new relevance to education, as is being deliberated in current processes of mainstreaming ESD into a strengthened South African curriculum.

As is argued and shown across the book, ESD should strengthen holistic learning experiences, and facilitate lifelong learning, enabling learners to develop critical thinking and problem-solving abilities; consider environmental, social and economic aspects of human lives; and provide for action-oriented learning that helps learners to practice the knowledge they gained. ESD therefore involves learning to know, learning to do, learning to be, and learning to live together, sustainably.[1] These features of ESD are expected to be developed in an integrative way within and across several subjects.

The Handbook has developed into an accessible overview of a substantive body of research undertaken in South Africa, Mexico, India and Germany over an 8-year period in an international ESD ExpertNet[3] programme, which is carefully referenced in the handbook. From this, it offers an integrative approach to ESD through a synthesis of situated learning, drawing on heritage and existing knowledge of learners, foregrounding ethics-led pedagogical inquiries that support acquisition of new knowledge, deliberative inquiries that support practical actions and transformative approaches to learning that build competences and values for sustainability.

The handbook is divided into three parts.

Part One is constituted of 10 chapters. Considering that the Handprint seeks to support teachers to assist learners to understand and deliberate matters of concern, the 10 topics offer practical guidance to teachers to "…clarify and plan how to mediate ESD as evaluative learning around local matters of concern and towards Handprint learning actions that will contribute to future sustainability" (p. 2). Part Two offers a selection of four exemplars that provide illustrative starting points, and educators are encouraged to use this to plan their programmes or adapt these into their own contexts around local matters of concern. Most of the examples have been developed around real-world start-up stories that invite learners to share their "own stories and experiences and to raise questions for learner-led inquiry, evaluative deliberation and action" (p. 2). Part Three is presented mainly as two picture stories. These are illustrative of a methodology to promote and encourage learners to make observations of matters of concern in their daily lives and to share their own stories and experiences. As such, the pictures are illustrative of how learners experience, can reimagine and tell transformative stories of living together and ensuing positive, ethics-led learning and change in a changing world.

This book is a valuable resource for teachers and teacher educators. It is also valuable for sustainability scientists wanting to reach out to teachers and schools with findings from their science programmes for its action-oriented, and ethics-led approach. Importantly, it shies away from 'issues messaging' to children, and instead promotes situated, collaborative learning approaches that encourage critical thinking and inquiry-based approaches to learning our way towards sustainability. For the same reasons, the book is useful for all who wish to work with teachers in primary and secondary schools to mainstream or integrate ESD into the formal education system, including curriculum developers and textbook writers. The authors have managed to position and demonstrate that the concept could be used as a cross-cutting theme that runs across all curriculum subjects and learning contexts.

Although the handbook offers a practical approach to teaching ESD through an ethics-led deliberative approach, the focus on the 'Handprint CARE' pedagogy might require some contextualisation by adapting to existing educational frameworks and alignment to local curricula. Further, case studies presented by the handbook are not exhaustive. Further examples across different subjects and from different learning contexts can be explored for more effective

learning interactions. New findings from the sustainability sciences can also lead to emerging case studies.

Handprints for Change: A Teacher Education Handbook – Activating Handprint Learning Actions in Primary Schools and Beyond is a well-structured and inspiring guide for science engagement, educators and teacher educators who strive to empower future generations to become responsible and active stewards of the environment. As a teacher educator, and sustainability scientist, I appreciate its emphasis on ethics, collaboration, and real-world action. This practical and deliberative approach makes it a valuable contribution to ESD, and to sustainability science engagement.

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The value of citizen science for a just and sustainable water future

Significance:

In this Commentary, we reflect on advances regarding citizen science monitoring of water systems in South Africa and how research into water-related citizen science can shape just transitions to a water secure future.

South Africa is characterised by a triple challenge of multidimensional poverty, inequality, and unemployment. The official unemployment rate is 32%, which worsens when considering that youth (ages 15 to 34) unemployment stands at 46%. The most recent General Household Survey reports that 23.1% of South African households have less than adequate access to food, and that almost 40% of households now receive a social assistance grant.[1] South Africa also has the highest Gini coefficient (i.e., the disparity between rich and poor) in the world.[2] These issues challenge our ability to make sustainable, equitable, efficient, and just transitions toward a food and water secure future. A bleak portrait! However, this background is important to appreciate because, although these issues may seem solely socio-economic, they are intricately intertwined with environmental health and the state of and pressure on our natural resources.

Everything starts with water: it is the life support system that underpins everything else. Yet, globally, freshwater systems are in crisis from pollution and mismanagement.[3] Healthy people and food security, foundational for uplifting people from poverty and inequality, require healthy, functional freshwater ecosystems and, especially, good-quality water.

At the source, poorly treated wastewater, sewage leaks, illegal dumpsites, mismanaged mining waste, poor agricultural practices, and invasive alien plants are combining as a potent medley for degrading natural freshwater sources. At the supply end, the most recent South African Department of Water and Sanitation (DWS) No Drop Report shows that an estimated 47% of South Africa's clean, potable water is non-revenue.[4] Essentially, nearly half of South Africa's clean, processed drinking water is either lost, wasted, or supplied without payment.

Problems with water are not uniquely a South African issue – approximately 2.1 billion people lack access to safe drinking water and 3.6 billion lack access to safely managed water-related services. These issues typically most severely affect marginalised communities, which usually have the least agency over their environmental conditions or water resources and the least access to quality education regarding water, sanitation, and hygiene. In this way, communities exposed to poor water quality or water pollution face compounded hardships. This is especially the case for rural and peri-urban women and youth, who are often the most vulnerable in society.[5]

The upside of this situation is that marginalised and vulnerable people have the most to gain from social inclusion in the water commons. Unemployed young people stand to benefit significantly from learning to understand and care for water, soil, food, and nutrition, engaging in science and sustainability practices and, as they learn, developing 'green skills' that could help them gain employment within the Green Economy and improve livelihoods. This is possible through citizen science (also discussed using other terms such as community-based monitoring or participatory science).

Citizen science has been around, in various forms, for a long time. From tracking the flowering dates of trees in the ninth century, to monitoring the arrival dates of migratory birds in the early 20th century and helping map the night sky today, citizens have been making important contributions to science for hundreds of years. Over the last decade, citizen science has begun to boom, as greater value is placed on co-developing knowledge and solutions both for *and* with people across sectors. Recent advances in citizen science for water quality monitoring present a particularly exciting vehicle for accelerating citizen science into the mainstream scientific discourse and national monitoring regimes, and into progress towards sustainability and transitional objectives such as the Sustainable Development Goals (SDGs).[6]

Worldwide, there has been a surge in the number of citizen science initiatives focused on water, supported by the development and refinement of various innovative tools and techniques.[7] This growth has been in response to recognising that conventional science approaches are simply not adequate for generating the volumes of data, both spatially and across time, required to inform efficient and effective adaptive management strategies for critical water resources. Moreover, citizen science engages people in identifying and solving local problems with their water and environment – a far more potent method for eliciting meaningful change than traditional top-down approaches.[8] Citizen science water quality monitoring has the potential to improve people's environmental awareness, scientific literacy, and understanding of the mechanisms and importance of water-related concerns, and opens channels for communication with water authorities. Ultimately, this gives them agency around monitoring and governance in the water commons. Citizen science also allows for qualitative data generation and understanding, for example, capturing indigenous knowledge of the cultural value of certain water resources – data which are vitally important but typically not captured through conventional methods.[9] These are all critical features of just transitions towards an inclusive, resilient, and sustainable future for all.

The advances made in South Africa, in particular regarding citizen science monitoring of water systems (i.e., rivers, streams, wetlands, groundwater, and estuaries), especially over the last decade, have been substantial.[10,11] Examples include: the formation of the Water Research Observatory by the Water Research Commission (WRC), which serves as an interoperable repository for water-related data to assist in centralising a usable database

from which to make management decisions; research by the Agricultural Research Council (ARC) and WRC piloting the inclusion of citizen science water quality data from smartphone apps for measuring nitrate or phosphate concentrations, such as the Deltares Aquality app, into the national monitoring programmes; development of a citizen science version of the WET-Health Assessment tool for wetlands, miniWET-Health; pioneering the use of clarity tubes for monitoring total suspended solids and water clarity of wastewater treatment works effluent and rivers[12]; refinement of transparent velocity head rod (i.e., velocity planks) for estimating stream discharge[13]; the Habitat Condition Scale (HCS) and African Dragonfly Biotic Index (ADBI) biological indices for assessing ecological condition and water quality[14]; the Diamonds on the Soles of Their Feet initiative for groundwater monitoring[15]; the inclusion of the Virtual Museum OdonataMAP and FrogMAP citizen science distribution databases within the Freshwater Biodiversity Information System (FBIS)[16]; and recent upgrades to the citizen science biomonitoring tool mini stream assessment scoring system (miniSASS), including a refurbished website with open access data interaction and visualisation paired to a new miniSASS app[17].

The developments with miniSASS are exciting in terms of global scaling, given that miniSASS has been highlighted by the United Nations (UN) as a potential tool for monitoring and reporting against SDG 6.3.2 and 6a-b[18], with linkages to the powerful Freshwater Watch global freshwater monitoring environment, another citizen science water quality monitoring system advocated by the UN[18]. The miniSASS mobile app is also piloting the use of artificial intelligence (AI) to assist the user in identifying aquatic macroinvertebrates sampled during a miniSASS survey to improve data credibility and enhance data integration potential into national water monitoring schemes.[19] This represents an exciting avenue for upscaling citizen science water quality monitoring data validity and accessibility, both vital to global uptake and trust building within scientific discourse.

Despite the progress, both technologically and regarding scientific perception, the challenge in scaling up the power and utility of citizen science water quality monitoring remains. There is a requirement for social policy enablers that will contribute to bottom-up community-based solutions and practices for better management of water and environmental resources and sustainable development. In this regard, it is important that citizen science tools are applied in a multitude of contexts and are continuously adapted and refined through research to stay relevant and aligned with local and global goals. These tools and techniques need to facilitate meaningful engagement within communities, allowing them to monitor their freshwater ecosystems and to contribute credible data to their local water authorities.

One of the prime South African examples of the use of multidimensional citizen science to co-engage communities to gather data and contribute to the governance of their local environments is the Enviro-Champs (also known under other names, for example, the Amanzi-Champs, Witzenberg Water Savers, or Eco-Champs).[20] The Enviro-Champs initiative co-engages people situated in communities who are in touch with local environmental challenges and builds capacity amongst them to monitor their water resources. The initiative empowers the participants to use their data to interact with water authorities and bring about positive change within their communities. Over the last 15 years, the efforts of the Mpophomeni Enviro-Champs in KwaZulu-Natal, South Africa, using citizen science tools to monitor their streams and report overflowing sewerage manholes, water leaks, and illegal dumpsites to uMngeni-uThukela Water (i.e., the local water authority) elicited the attention of the South African National Biodiversity Institute (SANBI) and other institutions that collectively assisted in addressing local environmental issues.[21]

The advances made in citizen science for water monitoring and the documentation of Enviro-Champ style models have collectively built an understanding of how to improve learning about these citizen science tools. This has increased the potential for scalability of citizen science for the biomonitoring of water systems. The development of online learning modules, initiated through a research project supported by the WRC, in which a learning programme was piloted and co-adapted within a rural community in Northern KwaZulu-Natal, is a case in point. This case involved facilitating online learning about citizen science tools within a community that had limited access to the Internet and building an understanding of the obstacles to learning and how those could be overcome. The outcomes highlighted the importance of maintaining social learning processes through the application of the Action Learning Framework, open discourse, and practical hands-on activities, all of which combined to enable participants to develop meaningful relationships and co-create solutions to the challenges they faced.[22]

What these examples show is that when citizen science is truly co-created, supported, and recognised by local government, it can generate vital data for often data poor regions and initiate positive change within a community. There are now citizen science tools that have been developed, recognised, or refined to become widely applicable within the sub-region. There are systems in place that allow more people to learn how to use these tools and which improve the understanding of how to best support this learning. From a data perspective, researchers and practitioners should continue to work on improving the validity and credibility of citizen science data to increase the acceptance and inclusion of the data into standard reporting methods at local, national, and global levels. However, citizen science engagement goes beyond data collection. It is a co-learning and co-development pathway for people that generates significant benefits for people and livelihoods. Through engaging with citizen science, young people acquire situated learning knowledge and significant career pathway skills, which will stand them, and their communities, in good stead for the rest of their lives. These benefits may be hard to measure, but we encourage all citizen science initiatives to attempt to document them. These processes of co-learning and co-developing solutions may prove vital for creating just and sustainable water and food security for all in the future.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. All authors read and approved the final version.

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What does practising the Adaptive Systemic Approach offer engaged sustainability science?

Significance:

Engaged sustainability science is a relational response that mobilises knowledge into constructive action. However, theoretical and conceptual development has outstripped effective practice. Some of the barriers to practice include: (1) integrative theories, concepts and vocabulary that are not familiar to most disciplinary scholars; (2) literature that supports these perspectives is dispersed and difficult to organise into practical steps; (3) the skill-set for effective engagement is rare, and includes facilitating co-learning that is attentive to power and equity. By providing a clear set of activities, the Adaptive Systemic Approach enables novice and experienced research practitioners to start, and to follow a pathway.

Introduction

The sustainability crises of the 21st century will not be addressed by academic knowledge alone, and certainly not by discrete disciplines. This recognition lies at the heart of engaged sustainability science. There is clear evidence that the 'wicked' problems that beset the earth's complex social-ecological systems, require multiple, concurrent interventions informed by diverse knowledge forms.

The Adaptive Systemic Approach (ASA) was designed by teams of researchers from across Africa, to provide a clear pathway for sustainability research to effect change towards improved ecological health and social justice.[1] The teams were assembled through the African Research Universities Alliance (ARUA), which placed the Water Centre of Excellence in a 'science' research stream, so the initial members were natural scientists (aquatic and landscape ecologists, botanists, hydrologists, and water or agricultural engineers), only a few of whom were experienced in sustainability science.

Here we show how the African research teams took the initial conceptualisation of the ASA, and, through a collaborative project entitled 'Unlocking resilient benefits from African water resources' (RESBEN), learned ways to advance engaged sustainability science practice. RESBEN addressed the intertwined problems of freshwater scarcity, impaired water quality, and declining ecosystem health, and was organised through a hub/lead university team from South Africa, with 'node' teams from Ethiopia, Senegal, Nigeria, Uganda, Rwanda and Tanzania, and three researchers from the UK.

RESBEN was ambitious, and we were naïve – even those of us with transdisciplinary, engaged research experience. As we encountered setbacks and challenges, we realised we had to constantly review our work 'warts and all'. In messy engaged research projects, processes and outcomes are often 'back polished', but we decided to resist this approach and rather to engage as a team with 'radical honesty' – the open acknowledgement of, and reflection on, limitations and failures.

The ASA practice was uncertain and non-linear. Through time, teams recognised three main characteristics. (1) There is a 'bubble' (community of practice) of scholars familiar with engaged sustainability science vocabulary, concepts and practice. Most RESBEN researchers were outside the bubble. It took much longer to become familiar than we had anticipated. (2) The ASA provides a flexible architecture that supports practice and allows for learning and adaptation in the face of disruptions. (3) The architecture is only effective when there are mechanisms – developed through team capability building – that ensure that participants experience being respected and have adequate vocabulary and confidence to share their knowledge and to learn. Mechanisms attentive to epistemic (in)justice (un/fairness in terms of knowing) are: (i) your knowledge being respected and (ii) having sufficient additional knowledge provided to participate effectively[2] (Figure 1).

The ASA: Concepts familiar in the 'bubble' architecture, and mechanisms of practice

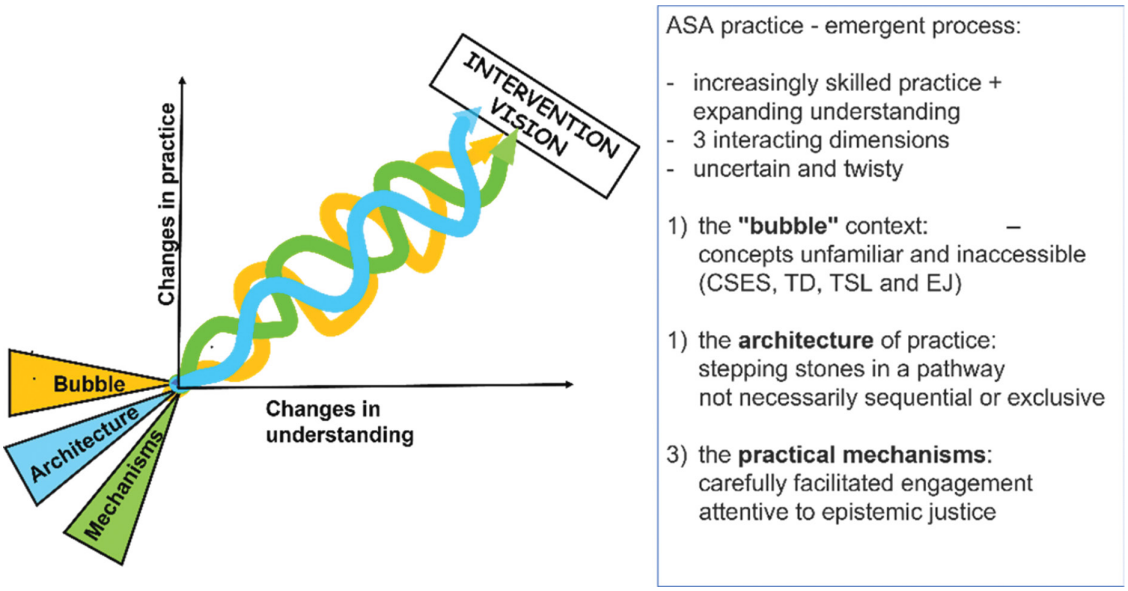
The ASA had three, and later four, foundational concepts that provide a basis for practice.

Complex social-ecological systems

The world is understood to consist of linked, intertwined, and interactive social and ecological systems that behave as complex systems.[3,4] They comprise many elements, linked by interactions that feed back to elements and other interactions, in an endlessly adaptive way. The interactive processes are unpredictable, non-linear and are influenced by scale and system history. Intervention outcomes can exceed or be the inverse of effort and investment. It is imperative to take account of context. As a result, intervention pathways *are* twisty and uncertain, and *progress is adaptive and towards* a planned outcome or state – rather than *achieving* a specified outcome or *solving* a problem.

Transdisciplinarity

Transdisciplinarity[5] is a commitment to respecting and including people with the widest possible range of knowledge forms (scholarly – from the widest relevant range of disciplines, indigenous, personal, practical, and professional) and using knowledge responsibly and inclusively to address intractable problems. (For details of RESBEN's disciplinary scope see Palmer et al.[1])



CSES, complex social-ecological systems; TD, transdisciplinarity; TSL, transformative social learning; EJ, epistemic justice

Figure 1: Through time, the REBEN teams experienced the way in which the three aspects of the Adaptive Systemic Approach (ASA) – recognising the bubble, following the architecture, and learning the practical mechanisms of skilful facilitation – interacted, enabling more nuanced understanding, and progress, in a twisty and uncertain manner, towards the vision of the research intervention planned in each of seven African countries.

Transformative social learning

Transformative social learning[6] involved mobilising knowledge to enable co-learning among groups of people, often through collective action and collaborative activities. Transformation emerges in the relationship between changes in understanding and doing.

Epistemic justice

Epistemic justice[7] means fairness in relation to knowing. When people participate in engaged sustainability activities, epistemic justice depends on each person experiencing being respected, and having sufficient understanding, knowledge, vocabulary and confidence to both take in new knowledge and to share their knowledge.

Following the pathway

There also are other complementary concepts, framings, and methods that are well aligned with the ASA and can add value. Examples include critical realism, nexus thinking, systems thinking, value creation, and causal loop diagramming.

The architecture of the ASA is a set of phases and stages that support and enable the strategic adaptive management of complex social-ecological systems (Figure 2). By providing a set of sequential and concurrent activities, the ASA enables novice and more experienced research practitioners to start – and provides a guide and pathway to follow. Although it is not prescriptive, our practice has found that the ASA phases work; they are detailed in Palmer et al.[1]

The ASA journey

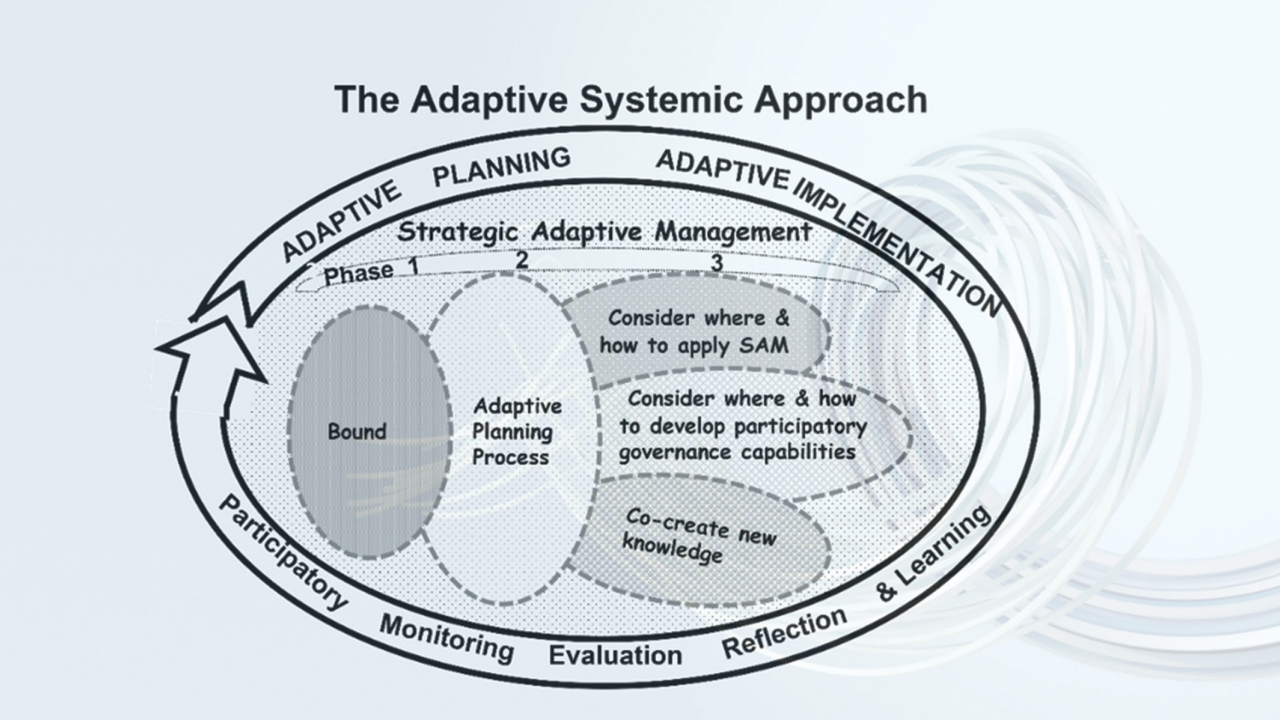
In this section, we work through the RESBEN timeline, commenting on the way that key selected engaged activities, in and across countries, progressed us along the interactive pathway shown in Figure 1. We underline the six (deceptively simple) insights that practising the ASA offers to sustainability science. We present this as a timeline to reveal path dependency, emergent properties and feedback in the RESBEN project system.

In **February 2017**, the teams of researchers met each other face to face for the first time at the Water Centre of Excellence launch, which included a four-day workshop. Shared languages included English and French – and translation was available. Drawing on facilitation skills learned from epistemic justice-attentive Strategic Adaptive Management[8], the group was guided to co-develop a conceptual map of our agreed research practice (Figure 3) – the forerunner of the ASA. We also socialised and built interpersonal relationships. These four days were to prove a vital relational foundation.

At this early stage, we agreed to: a complex social-ecological systems framing; seeing research as a process to grow knowledge *and* benefit people; and to understanding healthy ecosystems and ecosystem services as supporting human well-being. We had little grasp of what it would take to actually *do* this.

From **March-December 2019**, RESBEN researchers collaborated to develop proposals, and were awarded two grants to develop research capacity and capabilities, and to apply the ASA in seven African countries. Each country-based case study was selected in a complex social-ecological system with established stakeholder relationships, and a sound contextual understanding.[1] Stakeholders explicitly spanned government, civil society, NGOs, residents of the complex social-ecological system, and private enterprise. They were initially identified by the research team during Phase 1, 'Bound' (Figure 2), and were added incrementally throughout the project. Stakeholder relationships were deepened at the interactive workshops. It is worth taking/making as much time as possible to build trusted relationships. Relationship dimensions include personal, professional, scholarly, and practical interactions, within teams, and with stakeholders.

In **March 2020**, the hub team developed a short course and organised a four-day ASA training workshop in Ethiopia, for lead researchers from all the nodes. The course was well received, and we did not realise at the time that what was presented was "too much too fast" (Ugandan researcher). At that stage, we envisaged that RESBEN would unfold as a series of workshops for each of the ASA phases, in each country, and that hub researchers, experienced in ASA concepts and facilitation, would lead workshops as vehicles of learning by doing. The COVID-19 pandemic intervened and face-to-face meetings and travel were suspended for two years! At the time, we did not realise how thin understanding was of complex social-ecological systems, transdisciplinarity, transformative social learning and epistemic justice. This was the first of iterative 'training of trainers' work sessions in which experienced hub researchers worked through concepts and processes with country-based researchers, who designed and planned their APP workshops to suit their context, and actively practised new skills. Each activity was reflexively discussed, and co-learning was explored. Now, four years later, most RESBEN researchers remain disciplinary specialists, but they are willing and able to collaborate in transdisciplinary engaged projects, in an informed and generative way.



Source: Palmer et al.[1] (reproduced under a CC BY 4.0 licence)

Figure 2: "Schematic of ASA [Adaptive Systemic Approach] showing phases of the process and learning cycles, with iterations indicated in a forward spiral."

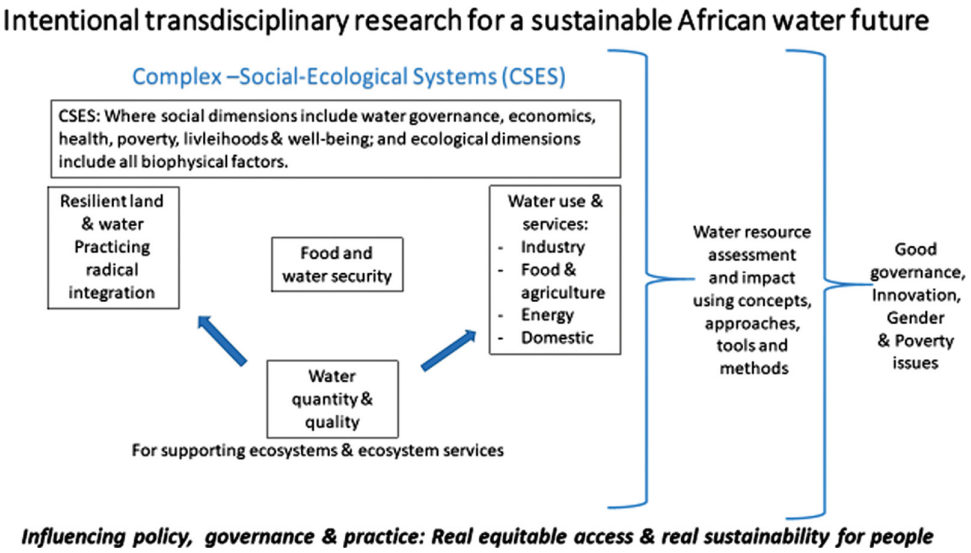


Figure 3: Forerunner of the Adaptive Systemic Approach (ASA), a conceptual mapping of agreed research practice among ARUA Water Centre of Excellence researchers.

Between April 2020 and April 2021, we confronted the enormity of the pandemic disruption. The ASA way of working is informed by principles of practice[9], of which 'manage discontinuities' is the one that is repeated at different degrees of severity in every engaged complex social-ecological systems project. RESBEN had to be re-planned several times, affecting key processes.

i) *Students:* RESBEN had (at least) one science and one social science graduate student in each node. Their research drove ASA Phase 3 to "co-create new knowledge" (Figure 2). Their projects were reformulated and initiated immediately to ensure graduation. ASA engaged workshops could not start. This created a discontinuity gap between research focussed on case study problems and the processes of knowledge co-creation with stakeholders. Once students could do field work, their one-to-two-year projects made invaluable connections with stakeholders.

ii) *Social science:* We started with 'science-heavy' research teams. With a clear transdisciplinarity intention, we envisaged the lead social science researcher and a postdoctoral researcher from the UK overseeing social science students observing ASA workshops and formulating research questions related to ASA practice, with the opportunity for cross-case comparisons. Despite transdisciplinarity as a foundational concept, this was a fundamentally inadequate way to properly integrate natural and social sciences.

We belatedly located social science supervisors for social science students, but without budget allocations, and face-to-face engagement, there was a disconnect between node social science researchers and the project. It became clear that social science students needed methodological support, and the UK postdoc ran an online methods training programme.

We used 'power' as a linking concept, and ran an online power workshop – but it did not 'land'. Gradually we became aware of the magnitude of the divide between natural and social science sensibilities, theories, and methods. We underestimated what was needed to build bridges to grow understanding and interdisciplinary, and then transdisciplinary, knowledge. (Details of the case studies and research team are in Palmer et al.[1]) There were RESBEN researchers who remained dismissive of transdisciplinarity in the ASA, favouring 'hard' science. Among the willing natural scientists, there was still little understanding of what constitutes sound social science data collection and analysis – and the time and effort required to achieve this. Although RESBEN provided a social science methods course, and mentoring, for students and research assistants, this proved inadequate. The gap of omitting social science researchers from country-based teams at the start was too great to fill.

iii) *Funding:* Project funding was drastically cut, requiring radical replanning. This was discouraging and profoundly disruptive. It was at this stage that the depth of commitment and trusted relationships kept the project alive.

1. **Discontinuities are inevitable in complex social-ecological system projects (an emergent property of their complexity), creating disruptions of variable magnitude. Resilience comes from dogged perseverance, a pragmatic commitment to adaptation, and investment in trusted relationships among team members.**

2. **Real, deep, natural–social sciences integration is exceptionally difficult. This a frontier in engaged sustainability science. Understanding integrative concepts is required but insufficient. We still need to discover ways to robustly integrate social and natural sciences so that concepts, theories, methods, assumptions, vocabularies, ethics and sensibilities are shared, learned and respected.**

Between May 2021 and May 2022, country-based teams undertook the work required for the ASA phases. The 'Bound' phase should have resulted in a comprehensive social and biophysical contextual report on the 'problem system' to be addressed. (The term 'bound' indicates the porous boundaries of complex systems and the need for their delineation.) The social context should have included stakeholder mapping related to the problem being addressed, and initial stakeholder engagement initiated, so that stakeholders would be included as early as possible. Most reports were thin, and little stakeholder contact was evident – partly because of the pandemic. These reports were the first indication that the 'idea' of the ASA was not deeply understood and embedded.

The next phase was to assemble stakeholders identified in the 'Bound' reports, in an Adaptive Planning Process (APP) workshop (Figure 2) – which preferably should be over at least two days. (Stakeholders were identified by research teams based on their complex social-ecological systems contextual knowledge. The research teams sought stakeholders related to case study questions, paying attention to including participants from government, private enterprise and civil society – especially complex social-ecological systems residents.) There were formidable obstacles. Budget, time, and travel constraints led to adaptation. Node researchers gathered at the hub university, and we ran an APP 'training of trainers' work session, so that country-based researchers could lead and facilitate their own APP workshops. Training exposed researchers explicitly to facilitating in ways attentive to epistemic justice.[10] This was the first of iterative 'training of trainers' work sessions in which experienced hub researchers worked through concepts and processes with country-based researchers, who designed and planned their APP workshops to suit their context, and actively practised new skills. Each activity was reflexively discussed, and co-learning was explored.

One or two hub researchers travelled to support APP workshops now run by country-based teams. The effort to grow facilitation and engagement skills proved to be a better outcome than the originally planned hub-run workshops.

3. **Iteration is essential. Nuanced understanding and confident, careful facilitation only emerge with practice. Collective training and practice catalyses co-learning.**

4. **Facilitation that is attentive to epistemic justice is a core skill required for engaged sustainability research.**

After in-country APP workshops were completed, the whole team engaged online in an 'APP debrief', where outcomes were shared, and researchers learned from each other and discussed what 'worked' and what did not. This is where we drew on interpersonal trust, abandoned 'back-polishing', and accepted messiness. We experienced the need for, and benefits of *radical honesty* – acknowledging failures, and exploring ways to adapt. This was not easy. Time for reflective, honest debriefing conversations, and the of collection written and verbal reflections (elicited from carefully crafted questions) became vital tools for co-learning and discerning where value was created.

As APP workshops progressed, the hub team prepared a 'training of trainers' workshop for ASA phase 3, Strategic Adaptive Management (SAM) workshops – again facilitated by in-country researchers, with hub support. The aim of SAM workshops was to work again with stakeholders who, in the APP, had collectively co-developed a vision for the future of their complex social-ecological systems – and produced a set of linked objectives, with commitments to action, to move towards the vision. Stakeholders were reminded of their APP outcomes and alerted to the opportunities offered by adaptively moving toward an envisioned future.

In some cases, the SAM workshops brought a wider range of stakeholders together. Part of the facilitated workshop experience is that of sharing your knowledge and learning from others, and often being surprised at what you learn from whom. The benefit of facilitation that is alert to epistemic justice, is the creation of opportunities for listening, speaking and learning to occur among stakeholders who seldom encounter one another. Some of the mechanisms include using first names not titles, giving everyone a chance to contribute and recording their actual words on sheets put up on walls – creating the experience of being heard, and eliciting responses randomly, taking care to mix the order of conventionally senior people with others.

We found it particularly useful to run a 'learning words' session[10] with rural village participants, in their home language, before a more formal SAM workshop day. The community participants were encouraged to share their knowledge of the complex social-ecological systems in which they lived and derived their livelihood. They learned that the participants they would meet the next day would be less familiar with the place, and could learn from them. They in turn learned natural resource management terms previously unfamiliar to them, that they would encounter the following day at the SAM workshop. At the SAM workshop, the confidence of community participants and the willingness of government officials to share, listen and learn was unusual.

There was an explicit aim to expose stakeholders to the possibilities of participatory governance – where government includes stakeholders in planning and decision-making in the complex social-ecological systems of interest. The involvement of a wide range of stakeholders in the governance and management of complex social-ecological systems is rare – and where it exists is usually hierarchical, with evident power imbalances and exclusions. The SAM workshop acts as a learning catalyst to encourage movement towards participatory governance.

5. **Use a local language whenever possible, and translation when it is not, to ensure fair co-learning opportunities. Facilitate co-learning by arranging to expose participants to the vocabulary likely to be used in the workshop – and unlikely to be familiar to them.**

Between June 2022 and June 2023, the SAM workshops were completed, and the team committed to writing a set of papers for a special feature in a scholarly journal. We all met in Uganda for a final week of collaborative work. Again, the hub team carefully prepared a set of engaged activities for the teams and facilitated this final Integration Workshop. We asked ourselves the questions: What has practising the ASA in RESBEN contributed? How do we present these contributions in a scholarly manner?

The week was extraordinary. On the banks of Lake Victoria we worked to share what we had learned. We listened to our own stories of struggles, successes and failures at different times throughout the project. We articulated recognising the 'bubble'. We heard about the pressure of trying to work in a new way – to gather data in new ways, and to participate in the organisation and delivery of a large complex project. "When I saw an email from the project leader I closed my laptop and pretended it was not there. I could not read it for days." (Ethiopian researcher). We discussed the principles of practice that had emerged, and were excited about innovations in formal integration and the use of value creation to record research impact in a more nuanced way. For these details, the reader must wait for publication of that special feature.

6. **It is hard to write robust scholarly papers about messy engaged projects. But we must, and we must be honest about the realities and challenges of achieving an impact. We must also communicate generously and reflexively (academic literature, popular and social media, blogs and policy briefs, radio, television) to grapple with the challenges of engaged sustainability research, learning from each other as we go.**

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Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. The research proposal was reviewed and approved by the Rhodes University Human Ethics Committee (RU-HEC) with approval number: 2021-2818-6039. Both authors read and approved the final version of the paper.

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Investing in social learning processes to support science-engaged governance of strategic water source areas

Significance:

To address water challenges, several strategic water source areas (SWSAs) have been defined as important for water security in South Africa. The governance of SWSAs is faced with a series of interconnected tensions. The Living Catchments Project was implemented in four SWSAs, and provides an example of how social processes and learning projects can be funded, designed and implemented at different levels. At all of these levels, conceptualisation and evaluation of social learning processes are important for capturing the lessons learnt and advocating investment in community-engaged governance of SWSAs. Ongoing research is required for observing, examining and improving social learning processes in the governance of SWSAs.

Introduction

Strategic water source areas (SWSAs) are natural source areas for water that supply disproportionately large volumes of water per unit area and that are considered of strategic significance for water security from a national planning perspective.[1] It has been estimated that SWSAs in South Africa supply water for 60% of the population, more than 90% of urban water users, 67% of national economic activity, and 70% of irrigated agriculture.[2,3] This makes SWSAs crucial to the social, economic, and water security of South Africa. However, the governance of SWSAs is faced with a series of interconnected tensions which necessitate robust, long-term social processes and learning. At different levels of SWSA governance, social learning is key to nurturing the social capacities and capabilities needed to govern and collaborate amidst the complexities of SWSAs and their management.

Social learning in Living Catchments

Eaton et al.[4] state that social learning refers to information sharing and learning that enables actors within an expanding network to alter, or at least call into question, common knowledge on the issue or solution at hand, together with related stakeholders. Other researchers, such as Herero et al.[5] and Pahl-Wostl[6], focus on the types of change (individual, action and systemic) at different levels of the system that result from social learning. The Living Catchments Project (LCP) aimed to foster effective catchment governance through the establishment of communities of practice (CoP) (drawing on Wenger's[7] interpretation of social learning) working together in different groups across and within the living catchments to strengthen catchment management practices. It also sought to develop insight into the role of social learning in research and innovation policy and implementation through the use of transformational social learning approaches. Wenger-Trayner et al.[8] defined a community of practice as:

> *Groups of people who share a concern, a set of problems, a passion about a topic or practice, and who deepen their knowledge and expertise in that area by interacting on an ongoing basis.* (p.4)

CoPs are a helpful vehicle for facilitating social learning, through observing and supporting the deepening of enabling social processes, particularly nurturing relationship capital and relational agency to collectively develop shared practices. CoPs can bring together a wide range of individuals and foster continued connections and cooperation around common interests and practices. In the case of the LCP, water governance was the shared interest across the CoPs. In addition, the social learning focus of the LCP initiative aimed to provide safe places for collaboration, mutual learning, and cooperative problem-solving between researchers, communities, policymakers and implementers.[1]

The LCP was implemented between July 2019 and November 2023. The LCP provides an example of how social learning processes can be funded, designed and implemented. The LCP aimed to:

> *… create more resilient, more resourced, and more relational communities at both catchment and national scales, that are able to draw from the best that the research has to offer in the process of governing the equitable, productive, and sustainable use of water resources and ecosystem services.*[1(p.4)]

The LCP was implemented in four catchments that are linked with SWSAs for surface water across South Africa, namely, the uMzimvubu (Eastern Cape Drakensberg SWSA), Berg-Breede (Boland SWSA), Olifants (Mpumalanga Drakensberg SWSA) and the uThukela (Northern Drakensberg SWSA).[1]

At its core, the LCP, with its emphasis on social learning processes, aimed to deepen the relationships, connection, and co-learning between the varied stakeholders involved in the governance of SWSAs, such that greater long-term capacity for governance and resilience could be unlocked and sustained. The LCP ultimately implemented CoPs, led by locally appointed facilitators and champions who convened learning platforms in their respective catchments. The catchment conveners were appointed as follows: Environmental and Rural Solutions in the uMzimvubu catchment, Living Lands in the Berg-Breede catchment, Institute of Natural Resources in the uThukela catchment, and Kruger to Canyons Biosphere Region in the Olifants catchment. The different catchment conveners connected through engaged and safe learning platforms, and they also gauged the need for establishment of new learning platforms. The social learning took place through the learning spaces which the respective local champions

convened (new or already existing); this included the Catchment Indabas which persist even after the LCP has ended.

The CoPs aimed to deepen the capacity of diverse research, policy, implementation, and community stakeholders to learn and work together towards more resilient water governance in their catchments. This CoP work was supported by a series of collaborative research processes that deepened understanding of the role of social learning in the LCP, and surfaced implementation tools and policy advice, while facilitating social learning processes in SWSAs. Careful attention was paid to creating spaces for learning, both within SWSAs and between different catchments, to strengthen implementation and policy relevance. Social learning was designed at three levels in the LCP programme.

Level 1: Social learning as a feature of Transformative Innovation Policy

As a means to include people in the innovation process, the South African Department of Science and Innovation (DSI) developed the STI Decadal Plan (the Decadal Plan) which is geared towards shifting the South African National System of Innovation (NSI) towards having a more positive impact on the country's social and environmental priorities, in a manner that prioritises inclusive innovation, impact and investment in the NSI.[9] In support of its integrated goals, the Decadal Plan advises the importance of transdisciplinary social and research processes to analyse, quantify and develop a set of impact measures that can be utilised to recalibrate, refocus and scale up the contribution of innovation to socio-economic development.[9] A key theme emerging from the decadal plan is that science has to have social relevance, and if this is to be achieved it is going to be imperative to invest not just in multidisciplinary research projects, but also carefully designed social process programmes and collaborations that nurture the space for co-learning, collaboration, connecting and relationship building. The LCP was a national programme seeking to realise and contribute to the NSI.

Over the 4-year period, a potentially impactful story with certain key perspectives emerged from the LCP. This story includes evidence of (1) how the LCP facilitated stakeholder dialogue within and between SWSAs, (2) the formation of new partnerships in the implementation and research space, (3) the sharing of learnings and transfer of projects and pilots between catchments, (4) a closer understanding of how to co-create impactful research in these catchments, and (5) upskilling of youth and social learning facilitators, amongst others.[1] This level of social learning confirmed that the inclusion of society is imperative in fostering innovation and developing solutions that are underpinned by sustainability principles at the core. Science, technology and innovation (STI) are essential for solving societal issues and fostering a competitive, sustainable economy; however, as technology becomes more and more integrated into society and the economy, people should not be left behind[9] – people's learning in catchments at all levels is crucial for science and governance innovations in Living Catchments[1].

To evaluate and better understand this social learning at the level of innovation policy, the LCP team developed a draft theory of change for the evaluation[1], based in part on the Transformative Innovation Policy Consortium (TIPC) conceptual approach to transformative change, which includes a focus on transitioning systems[10], transdisciplinary co-engagement[11] and advancing social learning[1]. South Africa is a partner in the TIPC worldwide initiative through the DSI.[1] The TIPC is a 5-year programme with the goal of exploring possible transformation of innovation policy from a direct technological research, design and implement focus, to a focus that is more co-engaged and transdisciplinary, and that makes environmental and social concerns a focus.[1] The LCP, which is the first transformative innovation policy experiment in South Africa, is a component of a portfolio of experiments to trigger innovation for transformative change in the water sector.[12]

Level 2: Planning for and supporting social learning in the LCP

In working with the transformative innovation policy framework, the LCP project team adopted a lens for the observance of transformative changes in governance, interactions, relationships, connections, etc. in and across the LCP catchments and five CoPs. The transformative innovation policy framework offered 12 types of transformative outcomes[13], with the outcomes identifiable in individuals, groups, and organisations involved in transformative innovation policy programmes such as the LCP. These helped to guide evaluation of social learning across the LCP.[13,14] The LCP evaluation design enabled the LCP team to observe changes in water governance, organisational connections and collaborations at catchment and national levels around SWSAs. Transformative outcomes were defined, with transformative outcomes 1–3 focusing on the social learning intentions of cluster 1 of the Living Catchments project activities[1(p.5)]:

- *Catchment-based social spaces foster agency, trust, connection, convening, collaboration, co-creation, co-learning, and agenda setting between scientists, policymakers, implementers and local stakeholders working in SWSAs at the nexus of built and ecological infrastructure.*
- *Co-learning occurs within and between different SWSAs at the nexus of built and ecological infrastructure.*
- *Social spaces fostering collaboration and co-learning are sustainable and locally institutionalised.*

Transformative outcome 4 associated with the work of cluster 2 of the Living Catchments Project also emphasised social learning[1(p.6)]:

> *The science of transformative social learning facilitation is visible and valued by key institutions and individuals working at the nexus of water and ecosystems.*

And transformative outcome 5 associated with the work of cluster 3 of the Living Catchments Project emphasised social learning as follows[1(p.7)]:

> *Policy and associated advice (operating at the nexus of water and ecosystems) is articulated and mainstreamed in a way that is responsive to current needs, co-owned by key stakeholders and implementable.*

This work – in setting the outcomes of the programme with a focus on transformative innovation policy intentions – allowed for a means to evaluate and proactively support social learning endeavours. Evaluation of the social learning and the framing of outcomes that focus explicitly on social learning, enabled and strengthened the desire to invest in transformative social learning and to pursue alternative paths to traditional accepted norms of catchment management.[1] In other words, this allowed for an explicit focus on social learning, which was a policy innovation, as few other policy interventions provided such an explicit focus on social learning.[1] The major lessons which emerged from this focus in the LCP at broad programme level are:

- It is important to carefully map the social structures that are present on the ground in catchments, and then build from there.
- The facilitation of CoPs in and across catchments requires time and investment of resources (a budget is required).
- It is imperative to identify the right local champions (local conveners) to help lead CoPs within and across catchments.

This level of focus on social learning also identified that there is a need for ongoing research into how to observe and examine social learning, and how to improve the practices of social learning.[1] It was noted that a focus on the processes of social learning needs to be built into the design of social learning implementation projects[1]; this is addressed in the next section.

Level 3: Niche level advancement of social learning

Niche-level studies[15] were supported by the LCP via support of postgraduate research into the processes of understanding and advancing social learning amongst catchment stakeholders. These niche-level studies offer understanding of how transformative social learning supports boundary-crossing learning exchanges among diverse stakeholders in a community of practice, and can evaluate the

efficacy of social learning and transformation at ground level. One such study was undertaken in one of the Living Catchments, the uMzimvubu catchment, which is located in the former Transkei homeland and which is impacted by the contemporary difficulties of poverty and environmental deterioration. The catchment serves almost 2 million people, the majority of whom live in rural and peri-urban areas. As a result, there is an urgent need for water improvements that meet the increasing water demand (e.g. residential usage, agricultural) in order to improve the quality of life for those living in this landscape.[16]

A niche-level study was undertaken[17] to explore the importance of expansive learning as a method of social learning. Using this method from the learning sciences helped to make in-depth processes of transformative learning facilitation visible, showing *how* such facilitation can foster collaboration between different stakeholders in communities of practice to work towards the shared object of co-managing water resources. One of the tools to facilitate expansive learning (which is different from day-to-day learning in communities of practice) is the change laboratory method.[18] This method allows for explicit and concrete facilitation of learning by formative interventionist researchers[19] in ways that can assist the learning actors in the CoP to identify contradictions in their practices, to develop shared model solutions, and to express their collective agency.

An outcome of this research was that the research participants developed two outputs: a tool to monitor water issues in their communities and a management approach/strategy to assist in wattle management, which is a dire environmental challenge in SWSAs. It was recommended that the LCP should take up these process facilitation tools for working with multiple stakeholders who often share an interest in co-management but do not have the opportunities to co-engage and solve shared problems together. These methods can be developed further because they can be contextualised. Both solutions which emanated from the communities are important for the LCP endeavours and also for the greater TIPC work because they show that the live experiment, in this case at the niche level, yields benefits for collaborative management of the living catchments. Importantly, the methodological approach and tools emerging from the niche-level study are rooted in empathy and listening. These are two foundational processes necessary for embarking on transformative and transdisciplinary research in local contexts where diversity of context and issue predominate. These are not merely 'soft skills'; they are highly sophisticated skills, as they allow individuals or communities involved in interventions to voice their needs or desires.

Expansive learning is a form of social learning that gives more attention to a culturally and historically grounded expansive learning process with the potential to strengthen collaboration and transformative agency[20], especially regarding the inclusion of marginalised voices[17]. This gives meaning to realising the policy intentions and the LCP aspirations of contributing to transformative innovation policy via the TIPC. As noted above, an integral component of the DSI Decadal Plan for Science and Innovation involves investing in transformative social learning and innovation. Using expansive learning to bring together different stakeholders involved in managing water resources in the uMzimvubu catchment was an expression of investment in innovation which surfaced the voices of those most marginalised in catchment management policy and practice.

Conclusion

In this Commentary, we have offered insight into the importance of investing in social learning in South Africa's SWSAs, and we have shared experience of some of the key considerations of how to design and where to focus when implementing social learning projects. We have contextualised this within the wider policy arena that seeks to advance collaborative catchment management as a process of innovation in the South African water security policy landscape. This Commentary has opened a vantage point on different types and levels of social learning within this multi-levelled process, with each offering a different way of framing social learning, with implications for system and niche-level innovations and inclusion in the transition to more inclusive water management in South Africa. Although we did not focus on the challenges of the social learning approach, it is necessary to highlight that such approaches are not without challenges. For example, social learning requires time; it also requires careful facilitation and continuous support. This needs to be carefully planned for inclusion in institutional budgets as an explicit form of work. The work also brings to the fore the potential research questions that can inform the future work of the LCP. These include questions such as: (1) How can social learning enable bridging the gap between conventional science and traditional ecological knowledge at local levels? (2) How can social learning help to surface both insight into and practices of enabling the participation of local and other levels of stakeholders in decision-making processes? And (3) how can social learning facilitate co-management of living catchments involving all stakeholders in changing landscapes?

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. All authors read and approved the final version.

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Engaging with human-to-land relationships for engaged science: A complex-systems view for African land studies

Significance:

Given the extractive nature of many Western-led scientific activities in Africa, it is important to design research programmes that have long-term investments for (and on) the continent. These programmes must engage communities from local to regional levels to be sustainable, especially if they aim to achieve the sustainability of life systems continentally. In this regard, I propose and illustrate the value of using systemic approaches that focus primarily on the historicity and evolutionary nature of human-to-land relationships, which stem from shared identities, values, etc., to conduct engaged socio-economic-land studies as a subset of *social-ecological systems*.

Introduction

For the discussions in this special issue on 'Sustainability Science Engagement and Engaged Sustainability Sciences' I propose that our scientific methodology explores human-to-human and human-to-land relationships as the most important variable aspects of social-ecological systems, which contain socio-economic sub-systems. Readers are referred to a presentation by Biggs et al.[1] for a useful framing of the philosophical foundations (and implications) for approaching scientific inquiry using social-ecological systems principles. This orientation for exploration would entrench and guarantee locally grounded engagement for both science and policy.

Although I am presenting a mostly economics-oriented argument here, I am going to start off with some linguistics in the form of semantics. The nuanced difference in the meanings of the two words 'dweller' and 'citizen' is unfortunate for locally engaged science. At face value, I argue that the meaning of the word 'dweller', as 'a person or animal that lives in or at a specified place', fails to invoke an individual's emotional connection to that specified place and lacks the political commitment that individuals may have to fellow dwellers that makes the group a community. The word 'citizen', on the other hand, suggests stronger political *evolutionary* connectedness to a relevant geographical space and to fellow citizens who make up a nation as a group. However, those connections are mostly at a higher national level, as opposed to local connections to space and people at lower community levels. Engaging with evolving relationships intellectually and scientifically should include local to national and regional to global connections for effectiveness in communication and understanding. Some words in the Nguni languages capture these connections much better, thereby aiding the imagination and conceptualisation of 'locally engaged research' for exploring evolutionary human relationships that bind a mostly cohesive, homogeneous but evolving community through unifying cultural practices and purposes. Cilliers[2] would, for example, label these communities as *complex social systems* for scientific studies. The Nguni words that are better equipped for grasping such systems conceptually include '*aBahlali*' (in the isiXhosa language of southern Africa), which is often erroneously translated into the word 'dweller', but is understood by native speakers to refer to individuals, their neighbours and the changing relationships that exist among them and that make them a community. The word '*iZakhamuzi*' (in the isiZulu language of southern Africa) goes further in its commonly understood semantic emphasis on connection to place and space by also connoting permanency in the form of infrastructural investment made by individuals who make up some community. The literal translation of the word is 'home builders or constructors'. This is both at local and national levels. These are some of the useful concepts for understanding human-to-land and human-to-human evolutionary relationships that make up communities bound together by shared identities, language/s and resources through time. These relationships then guide individuals and communities on how to own and manage land as a resource, and to use and consume its natural resources sustainably, in most of southern Africa and elsewhere. It is also through the commonly shared meanings of vocabulary lists, phrases and sentences (that they construct) that we can also identify the norms and values embedded in the predominant relationships in society. Palmer et al.[3] provide a useful illustration of how words and their meanings from a local language are identified and used to enhance common understandings and group participatory governance in South Africa's landscape restoration.

Connectedness and relationships

It is therefore useful and important to think of *dwellers or residents* in land discussions, especially in southern Africa, as a *settler* group of people (with multiple and interchanging roles), and who are not only connected to the land they occupy or own, but are also a group of people who are connected culturally to one another through time. These cultural connections through function and meaning (with varied hierarchies) make for more obvious responses to questions of why and how human migrations, settlements and ensuing, sustained and sometimes intractable wars (or cooperative relations) over land and related resource stocks are not only economic or political, as described by Lund and colleagues[4]. Conflicts (or threats thereof) over land and its resources are also (if not mostly) about competing cultures, traditions and identities, as described by Motala[5] in the case of the Israel/Palestine conflict. In contrast, peace and cooperation are facilitated mostly by relationships of complementary but changing values, traditions and aspirations. In this sense, a *continuous* mapping of local connections to land and to other people in the form of relationships as institutions that define collective identities and cultures should be the main scientific guide and tool for engaged science at a local level and beyond. Beyond scientific

inquiry, the resolution, avoidance or deference of conflict and attainment of peace require us to invest in constant social, cultural and political engagement for policy aimed at sustainable outcomes. This goes beyond engagement only on technical issues in science or policy through descriptive discussions (e.g. Pakenham[6] in *The Scramble for Africa*, Lund et al.[4] in their presentation on land conflicts in Africa, and Harshe[7] on the effects of the Cold War and globalisation on Africa). The requirement to engage with changing community relationships at a scientific level demands from us *improved* understanding(s) of complex systems theory(ies) as methods of inquiry (e.g. Cilliers[2] and Preiser[8]). In my discipline of economics, the basics would include employing tools derived from understanding evolutionary social and economic institutions as custodians (or vehicles) of culture and norms that drive and regulate our lives as members of communities.[9,10]

A diverse sub-Saharan Africa

At local levels, the tools seem better equipped to not only encourage the interdisciplinarity and transdisciplinarity to which we aspire, but also to reveal the differentiated norms, identities, politics, and so on, across the different African regions, stemming from enduring legacies of different colonial histories. The locally engaged scientific approach toward differentiated and complex relationships (that are also evolving) with land and its resources is suitable, especially for regions like Africa, in which much diversity is encountered. As long argued by Amin[11], the lasting effects of colonial politics and management regimes on land resources left robust human connections to land (through identities, cultures, polities and economies) that are dissimilar across different sub-Saharan regions. Amin's[11] typology for understanding the continent is still useful. He identified at least three types of colonial legacies with respect to how land resources were (and in many spaces still are) used and managed. The different regions are (1) *settler*, (2) *cash-crop*, and (3) *concessionary* colonies. In settler colonies, land was (and in many cases still is) used by European settlers for farming and mining. Examples include contemporary South Africa and the former Southern Rhodesia (now Zimbabwe). In cash-crop colonies, indigenous peoples kept the land but were coerced into farming cash crops for exports to meet the needs of former colonial powers. This, to a degree, remains accurate for describing the contemporary economies of countries like Ghana or Nigeria. In concessionary colonies, land concessions were handed out to powerful European companies, some of which would total up to 70% of the colony (e.g. in the Belgian Congos (now the Republic of the Congo and the Democratic Republic of the Congo (DRC)). In the post-colonial period, there have also been some shifts in these categories. Zimbabwe, for instance, has evicted many of its white settler farmers, and Kenya has developed much stronger export markets in crops like coffee and tea for European consumption. This reflects the evolutionary nature of the relationships that defined communities and nations as complex systems. An example of a complex system that forms a sub-part of many social complex systems is a language system. Words derive their meanings and importance from the relationships they have to other words. Many words also play different roles in the sentences in which they are used (see Ellie and Larsen-Freeman[12]).

Engaging through a complex-systems approach

For locally and regionally engaged science and policy practice, I propose the study of temporal relationships, as focalised through *complexity theory*, and institutions (that are governed by societal norms and values) as treated in *institutional economics*, to establish regional group movements for *land and people relationship studies*. The policy practices and research activities of the groups would engage regional realities from within communities as evolutionary systems. The case study data would offer lessons for comparative analysis of what works and what does not work in a particular period to ameliorate conflict and move towards a peaceful state as primary goals for a sustainable continent. Building on these foundations, the research would then organically go granular, focussing on issues including best or most appropriate management or governance principles and sustainability options, as determined by the nature and form of the relationships (including market options) governed by local values and norms that are mapped out at local levels. In this sense, relationships among people and with land and its resources come out as more useful to understanding (even predicting) contemporary and future states of 'mostly competition and conflict' versus states of 'mostly cooperation and peace' based on the nature of the predominant relationships. This goes beyond merely looking at issues of scarcity, ownership rights regimes (public to private), transactional markets, and so on, as is often the case in technocratically oriented policy reform suggestions (see Detzner[13], Lund et al.[4] and others).

A comparative case study of a social system (Figure 1) of village stakeholders as *aBahlali* (who take on varied roles, including as small-scale farmers, traders, etc.) and all available markets for their livestock in the uMzimvubu River Upper Catchment of the Eastern Cape Province (South Africa), serves as a useful illustration for this institutional and systemic approach.[14]

In the study, an institutional comparison was made with a very different socio-economic system of small-scale farmers *as traders* at auction markets in Western Kenya. Lessons are drawn for each case in what is possible for nature conservation alongside sustainable livelihoods. In South Africa, in particular, relationships bound by tradition, trust and different forms of economic incentives matter for environmental

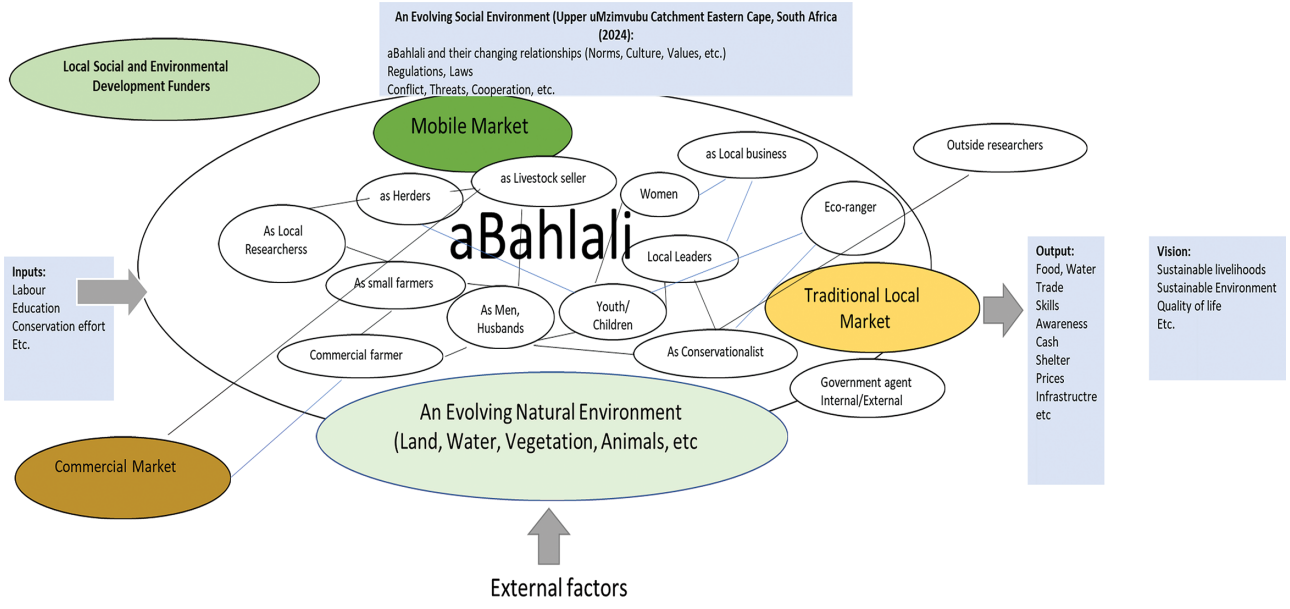

Figure 1: An evolving complex socio-economic system of changing relationship networks forming a community.

restoration efforts. *The Kenyan case stands out by virtue of its singular market-oriented approach, which is mostly competitive and efficient, but less accountable to the natural environment.* Although efficient, and therefore more enticing economically speaking, the latter is a case of a less sustainable option when viewed through a social-ecological system lens. Nevertheless, the cases contain plenty of lessons concerning what should be embraced and avoided, especially for policy formulation and practice. In the Eastern Cape Province system, where farmers are tagged as identifiable connected parts of a bigger social and ecological system, a stream of positive externalities (benefits) can be observed to characterise the system. In Western Kenya, where traders were almost anonymous as participants in frequent market auctions, a stream of externality costs characterised a system of low unit prices, leaving traders with marginal profits from stock sales. More studies of a similar nature (and better) on engaged social relationships are required for *engaged science*. The proposed regional science groups or clusters on *land and people relationships,* and many similar others, would be effective vehicles to drive this research and policy thinking forward.

Declarations

I have no competing interests to declare. I have no AI or LLM use to declare.

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Enhancing rural livelihoods and sustainability through a place-based approach to research

Significance:

This Commentary highlights the transformative potential of place-based research in rural development, demonstrating how a focused approach can yield deeper insights into the complex interplay between local institutions and sustainable livelihoods, ultimately leading to more effective and context-specific solutions.

Introduction

Place-based research delves into the intricacies of specific landscapes viewed as dynamic social-ecological systems, emphasising the interplay between human and natural elements. A place is not merely defined by its territorial boundaries and unique characteristics that set it apart from other regions. A place also serves as a focal point where various social, economic, and political forces intersect, intertwining with numerous biophysical and societal interactions and connections. The significance of place-based sustainability research has been increasingly acknowledged as indispensable in tackling intricate socio-political and ecological dilemmas. Innovations in landscape studies, particularly in sustainable rural livelihoods and communal land governance, underscore the necessity of place-based approaches due to the intricate nature of rural studies. Such an approach allows researchers to engage deeply with specific locales, and to understand the unique social, cultural, institutional and ecological dynamics. This depth of understanding is crucial for developing effective, tailored strategies to address these communities' specific challenges and opportunities.

Focusing research on a specific geographical area offers several advantages, particularly in a climate of declining research funding. By directing resources to a defined region, researchers can maximise the impact and prevent the dilution of efforts, thereby ensuring more substantial outcomes. This approach also fosters a robust research ecosystem by engaging local students, institutions, and mentors, who bring unique insights that enrich the research. Such a strategy can serve as a model for other regions or comparative studies across different geographies, highlighting the global relevance of local insights and demonstrating how region-specific research can contribute to broader, internationally recognised scholarship. This approach can facilitate international collaborations, where localised findings are synthesised to address global challenges, thus enhancing the universal applicability of the research.

In this Commentary, I share the experiences of our research unit in adopting a place-based approach to address critical challenges in rural development, specifically focusing on the institutional dynamics that impact sustainable livelihoods in the broader Alfred Nzo District Municipality. The central problem driving this research is the disconnect between local institutions and sustainable development efforts in rural areas, where conventional top-down approaches often overlook the complex realities of these communities. Our research unit sought to answer critical questions: How do local institutions influence the achievement of sustainable livelihoods? What is the role of network governance in facilitating or impeding these efforts? Additionally, I explore the necessary shifts within universities and the wider science environment to better accommodate and support place-based research. Drawing on examples from the Alfred Nzo District municipalities and network governance studies, this discussion highlights the importance of institutional support and interdisciplinary collaboration in achieving meaningful and sustainable research outcomes.

What is a place-based approach?

A place-based approach (PBA), in the context of a specific research unit, such as a research chair, involves integrating the local cultural, social, ecological, and economic contexts into the research processes and outcomes. According to Beaty et al.[1], PBA emphasises the importance of building solid relationships with the local community and the environment in which the research is conducted, thereby enhancing the societal value of the study. Researchers can achieve more accurate results and improve public trust in the scientific process by deepening relational engagement with a place's social-ecological context and history.

PBA and community-based research (CBR) are both methodologies that emphasise collaboration with local communities, but they differ in scope, focus, and implementation. For Watson et al.[2], PBA involves mobilising and coordinating local resources, services, and expertise across multiple organisations and sectors to strengthen historically disinvested neighbourhoods' social, structural, physical, and economic conditions. This approach often leverages partnerships with academic institutions to stimulate asset-based community development and address external accountability challenges through CBR efforts.[2]

In contrast, CBR is a collaborative method in which researchers assist with community-led projects, often with a social justice component. The hallmark of CBR is that the research is not designed and carried out solely by the researcher; instead, community members decide what information is valuable and how to collect it, ensuring that the research is directly relevant to their needs.[3] While both approaches emphasise partnership and collaboration, PBA tends to focus more on systemic changes and the coordination of multiple sectors. In contrast, CBR is more about empowering communities to lead the research process. Additionally, CBR in higher education often faces challenges in institutionalisation and visibility compared to other high-impact practices like service learning and undergraduate research, which limits its widespread adoption and the realisation of its full benefits.[4] Both approaches also emphasise ethical and sustainable community engagement, with mutual aid and reciprocity being critical elements in building trust and ensuring long-term impact.[5] Participatory action research, a subset of CBR,

further emphasises reflexivity, accountability, and sensitivity to power dynamics, challenging students and researchers to navigate new ways of working directly with stakeholders and contributing constructively to the community.[6] Thus, while both PBA and CBR aim to benefit communities, they do so through different mechanisms and scales of intervention.

By embracing a PBA, research units can effectively address the complex socio-ecological challenges that define rural and communal land contexts. This approach enhances the depth and relevance of the research and ensures that limited resources are utilised efficiently, fostering sustainable change and community engagement.

Successful place-based research projects often integrate local cultural, ecological, and educational elements to create meaningful and impactful outcomes. One notable example is the FAIR Island project in French Polynesia, which aims to enhance the reuse of scientific data and promote sustainable development by leveraging the institutional infrastructure of scientific field stations. This project increases awareness of ongoing research and connects it to societal benefits, thereby accelerating place-based research for sustainable development.[7] Another example is the action research conducted with educators to explore place-based education, where participants actively reflected on their professional work and advocated making 'place' an explicit pedagogical concern. This approach revealed new perspectives on the cultural and ecological life in which learners are embedded, emphasising the importance of place, belonging, and care in educational contexts.[8] Research in Freetown, Sierra Leone, has shown that leveraging local topographical and institutional resources can strengthen civic infrastructure and build confidence in city-scale institutions. This approach involves using place-based resources to mediate the impact of urban infrastructure developments, although these resources are often fragile and overlooked by city-scale practitioners.[9] From the preceding examples, it is clear that PBA has produced successful results elsewhere – but why is it important?

The importance of place-based research

The PBA for sustainable rural development involves recognising the diversity of resources within rural areas and enabling local agencies to shape their communities using these resources.[10] This shift from sectorial to territorial focus has benefitted many European rural areas, particularly in Portugal, by unlocking local potential, fostering sustainable practices, and enhancing social and economic well-being.[10] However, some rural communities face challenges, such as demographic imbalances and technical knowledge gaps, that hinder their ability to capitalise on these opportunities.[10] Working together at the interface of different rural development approaches, such as community-based, place-based, and territorial, could enhance collaboration among policymakers, practitioners, and researchers.[11]

Place-based research approaches for sustainable rural development in Africa have been crucial in addressing the challenges of failed agricultural markets, inappropriate policies, and natural resource degradation in sub-Saharan Africa.[12] Participatory rural appraisal is a significant step forward in designing effective rural development methodologies, as it appreciates the whole picture in rural communities and incorporates local people's perceptions, needs, and understanding.[13] Agricultural research organisations are pressured to make small-scale farming more market-oriented and profitable, necessitating participatory approaches to marketing and agroenterprise development.[14] Targeted approaches, such as the Enabling Rural Innovation framework, aim to identify different resource management strategies for specific households and communities in under-resourced areas and create balanced investments for sustainable rural livelihoods.[15]

PBA to research on sustainable rural livelihoods

A place-based approach was adopted for the research programme, with a focus on local municipalities within the Alfred Nzo District Municipality of the Eastern Cape Province, South Africa. This approach has been particularly emphasised in Matatiele Local Municipality, where extensive research and community engagement have been conducted.

The initial research in Matatiele Local Municipality revealed the intricate civic society and public administration structures. A baseline study using the Social Institutional Network Analysis tool was conducted in three communities within Matatiele, with the findings published in 'Rural livelihoods in South Africa: Mapping the role-players'.[16] Further research explored monitoring and evaluation processes in rural municipalities[17] and the causes and impacts of rural-urban migration[16]. These studies have been pivotal in understanding local governance and service delivery challenges in a rural context.

The programme has facilitated master's and doctoral research on various aspects of rural governance, decentralisation, and intergovernmental relations within Alfred Nzo District. These efforts have resulted in numerous publications in accredited journals, reflecting a strong commitment to generating impactful knowledge.

The PBA also involves active participation in local projects and structures. The research programme contributes to projects under the Umzimvubu Catchment Partnership, a consortium of voluntary organisations, public entities, research institutions, and communities focused on nurturing livelihoods in the Umzimvubu River catchment area. This partnership has led to successful research funding applications and ongoing projects funded by the Water Research Commission. Place-based research emphasises a locality's unique social, cultural, and ecological characteristics. In the Umzimvubu Catchment Partnership context, this approach has proven invaluable in understanding the intricate relationships between local and traditional institutions and livelihood activities on communal land.

Engagement with local municipalities through strategic planning and community meetings has strengthened partnerships with various stakeholders, including the Department of Agriculture, Land Reform and Rural Development, the CSIR, the South African National Biodiversity Institute, Ezemvelo KZN Wildlife, Environmental and Rural Solutions, and local municipalities within Alfred Nzo District. These collaborations have provided a unique opportunity to merge academia with practice, enhancing the research impact. There is a structured approach that prioritises regular and inclusive engagement. In this way, the critical voice and participation of the community do not get lost amidst the involvement of multiple stakeholders.[18] Specifically, under the Umzimvubu Catchment Partnership, quarterly meetings are held where community members, local organisations, and research institutions are given a platform to provide input, voice concerns, and receive updates on ongoing research and findings. These meetings serve as a crucial mechanism for maintaining transparency and ensuring that the perspectives of all stakeholders, particularly the local communities, are heard and integrated into the research process. This approach fosters equal involvement and ensures that the research remains grounded in the realities and needs of those it aims to serve.

The PBA has ensured the active participation of local communities, organisations, and institutions in the research programme's activities. This community participation has incorporated local perspectives into the generated knowledge, making the research more relevant and impactful. Furthermore, interdisciplinary research collaboration projects have addressed local rural issues and provided practical solutions that can potentially inform policy and practice.

The programme's research approach, while deeply rooted in local development, is designed to generate insights and methodologies that are applicable on a broader, international scale. By engaging in joint research with host community structures and promoting social responsibility among students, the Research Chair cultivates a model of community-based research that can be adapted and applied to similar contexts globally. The knowledge generated through this PBA is disseminated in international forums, publications, and collaborations, ensuring that the findings contribute to global discussions on sustainable development and rural livelihoods. Moreover, the Research Chair actively seeks to connect local research outcomes with international networks and comparative studies, highlighting how locally grounded research can inform and enhance global strategies, making the work both current and relevant internationally.

The value of a PBA for research units with limited resources

Place-based research emphasises the unique social, cultural, and ecological characteristics of specific locales. In the Umzimvubu Catchment Partnership context, this approach has proven invaluable in understanding the intricate relationships between local and traditional institutions and livelihood activities on communal land. Researchers can develop tailored strategies that address these areas' unique challenges and opportunities by focusing on specific places.

One of the primary benefits of a PBA is the active participation of local communities, organisations, and institutions in the research activities. This community involvement enables the incorporation of local perspectives into the generated knowledge, making the research more relevant and impactful. This approach ensures that efforts are concentrated in a defined geographical area for research units with limited resources, maximising the use of available funds and personnel without spreading resources too thin.

Another significant advantage is the establishment of research collaboration projects between different disciplines and organisations. By focusing on local rural issues and concerns, interdisciplinary research can provide practical solutions directly applicable to the community. This collaborative effort enhances the overall impact of research studies, as seen in the successful applications for funding from the Water Research Commission and the ongoing projects that have emerged from these partnerships.

Moreover, the PBA allows deep immersion into local projects and structures. This immersion fosters a thorough understanding of the local context, which is essential for developing sustainable and effective strategies. It also facilitates building solid relationships with local stakeholders, leading to long-term collaborations and support for future research initiatives.

A PBA is particularly valuable for research units with limited resources, enabling them to target a clearly defined geographical space. This focus ensures that the research addresses the specific needs and characteristics of the area, leading to more meaningful and sustainable outcomes. It also allows researchers to avoid the pitfalls of spreading resources too thin, which can dilute the impact of their work.

In conclusion, the PBA offers a strategic advantage for research units with limited resources by enabling short-term and long-term solutions tailored to local challenges. In the short term, this approach has led to the creation of practical toolkits and policy briefs that provide immediate guidance to local institutions on issues such as sustainable agricultural practices and water management. For instance, the Chair's research has produced toolkits that help local farmers implement climate-resilient farming techniques, which are shared during community workshops and through local government channels.

In the long term, the approach has fostered the development of comprehensive frameworks for sustainable rural development, which are reflected in academic publications and presentations at international conferences. These frameworks are designed to be adaptable to other regions, offering a blueprint for similar challenges elsewhere. Additionally, the ongoing community engagement has led to the development of best practices shared through policy briefs, further influencing regional and national policy. The cumulative effect of these activities ensures that the research addresses immediate local needs and contributes to broader discussions and solutions in the global context.

Challenges of adopting a PBA for research

A PBA is not without challenges; to effectively engage in a PBA to research, researchers must possess proficiency in the local languages. In the context of Matatiele, fluency in both Sesotho and isiXhosa, alongside English, is advantageous, given the prevalence of these languages in the area. Additionally, successful community entry necessitates individuals embedded within the community, possessing established trust and recognition by traditional leaders and municipal councillors. This embedded presence is crucial for securing community buy-in and facilitating research.[19]

Engaging with the community and obtaining consent from key representatives is vital for ethical and practical reasons. These include ensuring access to communities; fostering trust and participation among community members; respecting community protocols, culture, and knowledge; and enhancing accountability to the community. Moreover, the safety of research team members is significantly bolstered when community consent is secured. In deep rural areas, where residents are typically wary of outsiders and unaccustomed to external researchers, gaining the trust of gatekeepers and community members is particularly challenging. Fieldwork experiences in Matatiele underscored the difficulty of achieving this buy-in – a challenge that was mitigated by the invaluable assistance of the Umzimvubu Catchment Partnership. Numerous research institutions have leveraged the Umzimvubu Catchment Partnership as a gateway to conducting research in Matatiele and the Upper Umzimvubu catchment.

Another significant challenge of place-based research is the potential for research fatigue among community members. This issue was highlighted in one of the Umzimvubu Catchment Partnership's quarterly meetings, where participants expressed frustration over the lack of coordination among research institutions, leading to repetitive questioning of respondents. To mitigate this, the Umzimvubu Catchment Partnership proposed the creation of a centralised repository for research reports. This repository would enable institutions to review existing research, thereby preventing redundancy and ensuring that new inquiries build upon previous work rather than duplicating it.

Shifts needed in universities and funding institutions

Place-based research is essential for addressing local sustainability challenges and fostering resilient communities. To effectively support and advance this type of research, universities and funding institutions must adapt their structures and practices. The following recommendations outline the necessary shifts in institutional support, collaboration, funding mechanisms, and research evaluation to enhance the impact and recognition of place-based research initiatives.

1. **Enhancing awareness and support for place-based research:** Universities and funders can be made aware of place-based research's critical role in creating relevant, impactful, and socially responsible scholarship. This awareness can increase support and funding for initiatives prioritising long-term engagements with local contexts, ultimately contributing to more sustainable and equitable academic and community outcomes.
2. **Institutional support:** Universities should provide structural support for place-based research, particularly in remote areas. This support could include funding, administrative assistance, and recognition of place-based projects in academic promotion decisions.
3. **Collaboration and partnerships:** Building strong partnerships with local communities, government agencies, and NGOs is crucial. These partnerships facilitate the exchange of knowledge and resources, ensuring that research is relevant and impactful. The Umzimvubu Catchment Partnership exemplifies how collaborative efforts can enhance place-based sustainability initiatives.
4. **Funding mechanisms:** Funding agencies should prioritise and support transdisciplinary research projects. Such support involves creating grant programmes specifically for transdisciplinary initiatives and ensuring that evaluation criteria recognise transdisciplinary research's unique challenges and contributions.
5. **Research evaluation:** Traditional metrics of academic success, such as publication in high-impact journals, may not fully capture the value of place-based research. Universities could develop new evaluation frameworks to assess such projects' societal impacts, stakeholder engagement, and innovative approaches.

Declarations

I have no competing interests to declare. I used Grammarly and ChatGPT [4.0] to revise and edit writing, summate existing literature and improve readability.

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A lateral line organ for Slow co-engaged science for hot messes

Significance:

Surfacing the connections between science engagement, engaged science, and sustainability sciences, we urge a re-evaluation of sustainability science's beneficiaries and goals, by advocating a transdisciplinary approach to address sustainability challenges, based on a relational ontology. Thinking with posthumanist, feminist new materialist and Black feminist theories, we consider the importance of multispecies attention and empathy in scientific research. We propose a concept of evolving new perceptual organs in humans to enhance collective responsiveness, inspired by the lateral line organ in fish and their collaborative intelligence for navigating contemporary social and ecological crises and injustices in 'hot messes'.

Introduction

In this Commentary, we propose a co-engaged 'Slow Science' research in (and beyond) the natural sciences to trouble the perceived gap between science and society. The capitalisation of 'Slow' signifies a focus on depth and quality of engagement rather than simply moving at a slow pace in terms of time, aligning with the principles of the 'Slow movement', Such a research practice is predicated on a relational ontology, which sees the world as entangled and relationships as the way in which entities come into being, rather than assuming that the world consists of discrete, individual entities, with pre-existing characteristics or properties. Such a relational ontology alters the entire orientation of how science is practised, what is entailed in science engagement, and what the nature of an engaged science is. For example, when we consider 'hot messes', or what McGarry[1] calls "hot-stinky messes", to problematise or make messy the concept of sustainability, the notion of *intra-action*, is a crucial one. Intra-action is a neologism developed by the quantum physicist and philosopher, Karen Barad[2], as part of their relational ontological framework called agential realism. Barad distinguishes intra-action from interaction. Interaction assumes that individually constituted entities exist *a priori* and exert an influence, or act on each other, whereas intra-action disrupts this metaphysics of individualism by holding that entities materialise through the intra-action itself. From this viewpoint, individuals only exist in phenomena, where phenomena are "the entanglement — the ontological inseparability — of intra-acting agencies. (Where agency is an enactment, not something someone has, or something instantiated in the form of an individual agent.)"[3]

The warming world comes about through the intra-action of colonialism, capitalism and its most recent incarnation: the neoliberal market-oriented myth machine. Hot messes are necessary to move our thinking beyond the confines of sustainability, to allow for sustainability's shadow side to emerge. The future-obsessed (often historically blind), solution-driven orientation, which erases the reality of wicked problems[4], where solutions can lead to their own problems, feeds into multispecies extinction, GMO fallout, food insecurity, poverty, fossil fuel extractivism and its subsequent historical and contemporary displacement of people, ecosystems and worlds. All of which are fuelling the hottest the earth has been in recorded history. As Stacy Alaimo notes in her scathing critique of how science and objectivity are used to bolster the discourse of sustainability, it "proceeds with the presumption that human agency, technology, and master plans will get things under control"[5], when it is patently obvious that some humans (the privileged minority) have caused irreparable hot-stinky messes for the vast majority.

As such, a techno-scientific solution and future-driven approach to reified concepts like sustainability might not be the best response to such hot messes, particularly in the 'thick present'.[6] In South Africa, in the city of Durban in 2020–2021, we witnessed political insurrection, the COVID-19 pandemic induced lockdown and the worst floods in our history, over the space of 18 months. What allowed for citizens to respond to such a hot mess and sustainability crisis, was not the Sustainable Development Goals (SDGs), sustainability science innovation, nor sustainable government policies, but rather communities of care, which were responsive, had capacity for 'calling and responding' and that practised, convivial community-led meaning-making and citizen responses. As such, we feel it is important for scientists and engaged sustainability scientists to develop organs of perception, codes of practice and forms of rigour that allow for collaborative meaning-making and sense-making, in the thick present, that are also sensitive to the colonial, racist and violent histories that created modern scientific practices. The failures of sustainability science, from our perspective, are failures of perception, of sense-abilities, and of empathetic attentiveness.

The separation of science from social and cultural factors is a hegemonic ideology that blocks a more inclusive understanding of science's entanglement with various histories and worlds. Feminist science scholars, such as Donna Haraway, Karen Barad, Isabelle Stengers and others have challenged this separation and highlighted the porosity of the boundary between science and society. Furthermore, African scholar Bagela Chilisa[7] argues that traditional Western scientific methods may not always be appropriate or effective when conducting research in African contexts. She emphasises the importance of incorporating indigenous knowledge systems, cultural beliefs, and values into the research process to ensure that it is relevant and meaningful to the communities being studied. From an African perspective, science is seen as a holistic and interconnected system that values different ways of knowing, including spiritual and intuitive knowledge, in which knowing and knowledge is ecological and plural and not limited to individual forms of knowing.

Mkhize and Ntšekhe[8] show how idiomatic reasoning allows for conceptual pathways to be opened in meaning-making. Inspired by idiomatic reasoning, which oftentimes includes other animals, we draw on idiomatic reasoning

with fishes. Contemporary Black feminists like Alexis Pauline Gumbs[9] are developing their form of idiomatic reasoning through embodied scientific inquiries, such as learning from marine mammals. This process of empathetic encounters leads to the development of heightened sensory organs, altering how humans and scientists perceive themselves. Gumbs posits the undoing of traditional Western human definitions intertwined with separation and domination – something that has been keenly and painfully felt in South Africa, and the Global South.

As such, we imagine a new organ of understanding for sustainability science and engaged science, through imagining the growth of a lateral line found in fishes, an organ that might expand our conceptions of scientific education beyond our normative framings of school, classroom, curricula and pedagogies, into a shifting, dynamic, relational ontology, which merges with schools of fishes that change, pivot and respond with micro-empathetic adjustments to each other.

What would sustainable science say if we asked the right questions?

When thinking of how to engage sustainability science, we witness first-hand Vinciane Despret's[10] concept of "rendering each other capable", in which each fish's movements, ability to respond (or response-abilities) and attentiveness to each other, creates an empowerment that fosters interconnectivity, mutual imbrication and a shared relational agency. Despret[11] also asks, "what would animals say if we asked the right questions?", and we ask – how might Slow Science be used to render each other capable as forms of engaging in sustainable practices?

In order to consider how to ask such questions, we refer to a chapter which we co-wrote[12], in which we ask these questions of the physiology of fish. The chapter refers to our collective yearning for a Slow Science, in an attempt to move away from a science that is neutral, objective, or apolitical. We reinforce how scientific findings and research have real-world consequences that are deeply political, and influence justice in ways we often can never fully predict, and we argue that a central proposition for Slow Science is to develop a 'lateral line' organ of perceptivity, which is a science that is inherently a practice in solidarity.

The lateral line

The lateral line (Figure 1), present in most fish[13], is composed of fluid-filled canals running along a fish's body sides just beneath the skin[14]. This system is vital for sensing water movement and pressure, crucial for behaviours like schooling. Specialised sensory cells called neuromasts within these canals detect mechanical and hydrodynamic cues in the water. Neuromasts feature cilia sensitive to water flow, which bend upon contact to generate electrical signals to the fish's brain. Schooling offers fish benefits like predator protection, improved foraging, and better navigation, facilitated by the lateral line system for communication and group cohesion.

The concept of the lateral line could offer insights into understanding through fish physiology, insights into expanding our care and relational capacities in slow sustainability science, engaged science and solidarity science. We suggest that cultivating social perceptual organs (i.e. practices, principles, and ethics) could enable a form of solidarity akin to 'schooling', fostering a lateral awareness that directs our focus towards the well-being and ongoing iterative, attentive, affective relational encounters of those around us. If such a social organ could be cultivated within sustainability science, scholar activism and solidarity research, we could engage in knowledge co-creation that is responsive, caring, and accountable, prioritising attentiveness and responsibility in scientific endeavours.

Learning to move in the dark

Consider the ancient ancestors of modern fish, residing in an enigmatic world of perpetual darkness or turbid waters, that evolved sensory mechanisms that allow them to navigate and thrive in their environment; the lateral line system emerged as one such sensory adaptation, and is considered by some ichthyologists as the most critical sense for fish. We use the lateral line as a figuration, to surface ways of being, knowing and doing that could benefit from a peripheral 'distance touching' in how

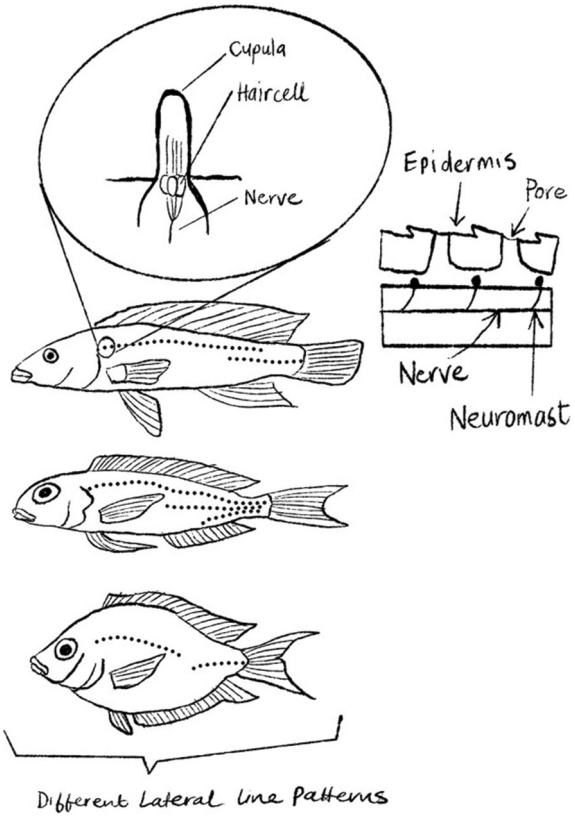

Figure 1: Fish rely on their lateral line system of fluid-filled canals housing neuromasts sensitive to water movement, essential for behaviours like schooling.

we inhabit and conduct scientific research. Inspired by Stengers' work on Slow Science[15], an engaged sustainability science must balance addressing broad societal issues with nuanced, specific analysis, reflecting the lateral line's ability to adapt to diverse environmental demands.

Touching the space between us

The lateral line in fish facilitates communication through detecting movements and vibrations, allowing for swift coordination within the school as fish sense changes in water pressure and temperature between them. This unique ability to 'distance touch' challenges the conventional idea of touch requiring direct physical contact, underscoring the importance of perception and sensory connections. How can we touch each other in this way, towards a collective response-ability?

The reef-dwelling cleaner wrasse (*Labroides dimidiatus)* is a vibrant small fish that is highly regarded for its careful and thorough cleaning habits (Figure 2). The fish set up designated cleaning spots on coral reefs where they cater to various 'customers', such as larger fish, by eliminating parasites and old skin cells. Cleaner wrasse play a crucial role in preserving the well-being of reef ecosystems. Their cleaning not only benefits the creatures they service but also contributes to controlling the transmission of parasites and diseases within the coral reef community. This symbiotic relationship illustrates the complex interactions among species in marine settings.

Predatory fish frequent these cleaning stations to rid themselves of parasites and shed skin. These predators temporarily cease their perpetual forward movement, their hunting activities and slow down, open themselves up to inspection while being cleaned, enabling smaller cleaner fish to fulfil their essential function in sustaining the ecosystem's health. Through these affective relationships, cleaner wrasse and 'client' become significant subjects and objects for each other where a deeper, more intimate touching and cleaning take place. In this way, bodies are rendered capable through their significance for each other, where each partner is changed in their encounter.

In the realm of science, equipped with a lateral line, 'distance-touch' and 'temporarily allowing ourselves for cleaning' speak to our ethical responsibility in how we engage with our surroundings. McKittrick refers to a form of science that acknowledges its past involvement in scientific racism and actively seeks accountability as it progresses forward. She explains that our understanding of Black life is created by interconnected but asymmetric (oftentimes sovereign) knowledge systems. Science is only a part of this exploration, tied to the other ways of knowing, being and doing in the world, but is also restless, uneasy, and multifaceted, rather than an absolute and oppressive force.

Sustainability science needs to slow down and allow itself to be cleaned of its past involvements in harm and racism, and develop an accountability that requires this stillness and vulnerability demonstrated by predatory fish and cleaner wrasse.

Schooling or shoaling?

The lateral line is vital in maintaining group cohesion among fish (Figure 3). When swimming closely together, fish's lateral lines are near each other, allowing them to sense the movements of nearby individuals, without bumping into each other. This continuous feedback loop (or what Kulundu et al.[16] referred to as "call and response transgressive learning" emergent in South Africa and the Global South) enables fish to adjust their swimming speed and direction to stay together, preventing straying or separation from the group. We emphasise the importance of research inquiries conducted collectively, iteratively, transparently, and ecologically, with a readiness to challenge conventional identities and disciplines, and move as an intuitive and relational collective.

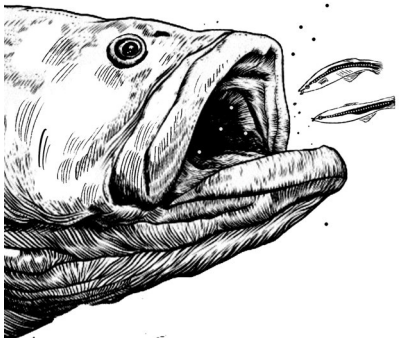

Figure 2: Cleaner wrasse cleaning the mouth of a predatory grouper. We explore this practice as a figurative practice of accountability in sustainability science.

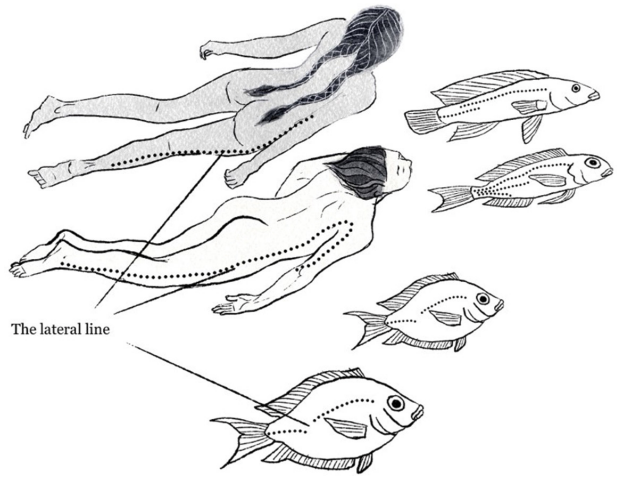

Figure 3: The lateral line in fish aids in maintaining group cohesion by enabling them to sense nearby movements without colliding. This feedback loop, known as call and response transgressive learning, helps fish adjust speed and direction to stay together. We imagine this organ to aid our think and theorising into the value of collaborative, iterative, and transparent research.

Bruno Latour[17] calls for matters of concern, rather than matters of fact, which was further expanded as "co-defining matters of concerns" by Lotz-Sisitka et al.[18], where concerns are surfaced iteratively throughout the research design, and this creates research that is more accountable, inclusive, responsive and based on principles of solidarity. Decolonial scholars reject the 'universalist' assumptions inherited from the Enlightenment era and advocate for a pluriversal approach to research, where research questions are collaboratively defined. Rather than seeking to capture and universalise knowledge, these scholar-activists employ various sources and narratives to question the act of capturing itself and the underlying motivations behind it. This is one way sustainability science can learn to shoal/school in dynamic processes of relationality.

Mkhize and Ntšekhe[8] discuss how pre-colonial forms of reasoning were inherently idiomatic, utilising idioms, proverbs, and myths as interpretive tools for understanding and responding to immediate struggles. This underscores the importance of storytelling and active listening as a lateral perception tool that could support the advancement of Slow Science. The lateral line could employ storytelling and active story-listening (engaging in both learning and unlearning) as a method of 'call-and-response' research, as one way of developing a lateral line organ. Kulundu et al. illustrate this concept by likening it to the practice of call-and-response singing in southern Africa. This iterative and continuous process of creating meaning serves as a form of 'endemic method-making', adapting to localised and contextual changes in our immediate environments. Just as a school of fish adjusts to an oncoming threat or obstacle in its dynamic aquatic realm, this involves embracing and grappling with unfamiliar or challenging ways of knowing that may lie outside our own belief systems or worldviews, fostering an inclusive approach to diverse forms of knowledge created beyond disciplinary constraints.

Slowing down fast science

How might this reciprocity enter into how we practise engaged science? What if we embraced the vulnerability of our science, seeking assistance in removing parasites and outdated concepts or philosophies through a thorough cleaning process? What does it require to become vulnerable and response-able in the very conducting of our research? How might we include others, not just in the collection of data but in the collaborative analysis and meaning-making? What might it look like to co-create claims from said data and analysis?

Perhaps we can answer these questions by first separating science from its alignment with neoliberalism and its associated logics. The commercialisation of science further impedes its effectiveness towards 'so-called' sustainability, and its servitude to society and ecosystem entanglements. The increasing corporatisation of higher education is likely to further impact scientific sustainability practices by fostering competition, promoting hostility towards perceived rivals, emphasising metrics such as Newtonian conceptions of 'impact' and publication outputs, exerting control over research outcomes, complying with managerial requests for reports, pursuing grant funding, and promoting the privatisation and commodification of knowledge for utilitarian purposes. The concept of sustainability science should not solely revolve around speed, efficacy and meeting future-orientated 'sustainability goals' but rather should prioritise in-depth, co-engaged, and present-time research that addresses pressing contemporary issues, incorporating past and future considerations.

Sustainability science in our current era should not be confined to serving industry or academia alone but should extend to addressing a wide array of social, political, cultural, economic, and ecological issues. Knowledge generated through scientific endeavours must not remain exclusive but should be disseminated in diverse forms to facilitate broad access and participation in knowledge creation.

We argue that this necessitates fostering an ecology of practices where diverse forms of knowledge are cultivated across various settings by different participants, allowing for cross-pollination of ideas and perspectives. Slow co-engaged science must transcend academic privilege and engage with the public to enable broader participation and

inclusivity, emphasising that academics are not isolated entities but part of a larger community that should actively involve diverse stakeholders in the scientific process. Moreover, science needs to embrace new modes of engagement, drawing inspiration from collaborative intelligence observed in fish communities as they collectively respond to threats for survival.

This shift towards collaborative science endeavours can be transformative, reorienting scientific and transdisciplinary studies through a diffractive approach that thinks with multiple disciplines and theoretical perspectives. As Stengers[19] highlights, an ecology of practices encourages experimental thinking, emphasising the importance of learning from encounters with others and questioning assumptions. This approach underscores the need for divergent modes of thinking, feeling, and acting, promoting a space where unexpected outcomes and novel insights can emerge, challenging preconceived notions and fostering openness to diverse perspectives.

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Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. All authors read and approved the final version.

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Doing just sustainability transitions: Facing the legitimation crisis in the Anthropocene today

Significance:

Undertaking just sustainability transitions in the context of the Anthropocene presents a complex societal challenge. This challenge is compounded by a systematic breakdown of confidence in the institution of science-making – the legitimation crisis. In this Commentary, we argue that addressing this challenge involves collaboration with diverse stakeholders and the application of agile research methodologies. Through innovative research tools, such as thick mapping and virtual reality, researchers and stakeholders can co-create and test new institutional arrangements that promote justice and sustainability. In this way, the scientific community can regain and maintain public trust while effectively addressing pressing global challenges.

Introduction

The challenge: Tackling societal transformation in the Anthropocene

As humanity grapples with the long-term consequences of anthropogenic actions, there is an increasing need for transformative social movements, including 'just sustainability transitions' (JST).[1,2] JST aims to improve the well-being of humans and other species while addressing the injustices associated with environmental degradation and species annihilation.[3] It is a deliberate attempt to move *away* from unsustainable and unjust societal conditions *towards* more sustainable and just alternatives, thus echoing Polanyi's[4] concept of a 'double movement'. Scientific research is critical in this movement. Yet engaging with transformative social processes in an anthropogenic context is too complex to be tackled within academia alone. Indeed, we are no longer working with natural processes that have evolved independently over time but with earth systems profoundly altered by humans. These changes are marked by persistent injustices in our society: by societal processes that favour the wealthy at the expense of the poor. Therefore, tackling JST requires a fresh and flexible methodological approach that moves between and beyond disciplines and often involves non-academics as key partners.

Multiple forms of knowledge require multiple methodological approaches. Engaging with JST processes requires understanding (Verstehen) and explaining (Erklärung) the conditions responsible for current unsustainable and unjust situations and exploring how to change (Verändern) these conditions. This complex challenge requires active collaboration between academic and non-academic partners, including informal stakeholders (citizens) and formal stakeholders, who have been mandated to speak on behalf of others. Together, these diverse research teams can co-produce three kinds of knowledge[5]:

1. Systems knowledge – factual knowledge of the causal dynamics of, for example, unsustainable/unjust situations.
2. Target knowledge – normative knowledge on what should be done to move away from these unjust/unsustainable situations.
3. Transformation knowledge – strategic knowledge on how to transition toward more desirable future situations.

These three different kinds of knowledge are associated with corresponding epistemic objects, including problem statements and research questions.[6-8] Yet none of these knowledge forms is exclusive to any particular research methodology. Conversely, each one can be produced through mono-, multi-, inter-, or trans-disciplinary research processes (Figure 1). Additionally, each of these processes has related characteristics and benefits. For example, when working towards transformative knowledge in the context of JST, research teams often adopt transdisciplinary methodologies as these approaches involve co-producing knowledge with non-academic stakeholders to advance social change. However, at the project's outset, it is not always apparent which methodology will be the most effective, and, in many cases, it is only possible to identify the best approach through the research process itself. Therefore, we recommend that scholars embrace methodological agility. This is discussed in more detail below.

What is methodological agility, and why do we recommend it?

Methodological agility is a meta-level research strategy in which research teams work to respond to the emerging needs of a project by switching between the research methodologies highlighted above.[9] We recommend methodological agility because we have found that applying a single dominant methodology to address complex societal challenges can advance instrumental, 'one-size-fits-all' solutions which ignore contextual differences and lead to path dependencies[10-13], contributing to the legitimation crisis discussed by Habermas[14]. This crisis represents a widespread lack of conviction in the normative/prescriptive production of 'scientific facts' about the world in isolation from society. For example, this crisis was evident in certain public reactions to the use of science to drive national policymaking during COVID-19.[15,16] However, the adoption of methodological agility can help researchers to re-build legitimacy by co-constructing just and sustainable pathways, rather than relying on fixed, unsustainable institutional arrangements. Moreover, in a context in which the institution of science-making is questioned and calls are made to include the public in scientific research, methodological agility and collaborative research approaches, in particular, emerge as powerful tools within the academy. Nonetheless, mono-, multi- and inter-disciplinary methodologies remain equally valid and are often key components of methodological agility strategies and related transdisciplinary research processes. Below, we highlight how researchers can draw on methodological agility to navigate dynamic contextual conditions that emerge, particularly when engaging with societal issues, such as JST.

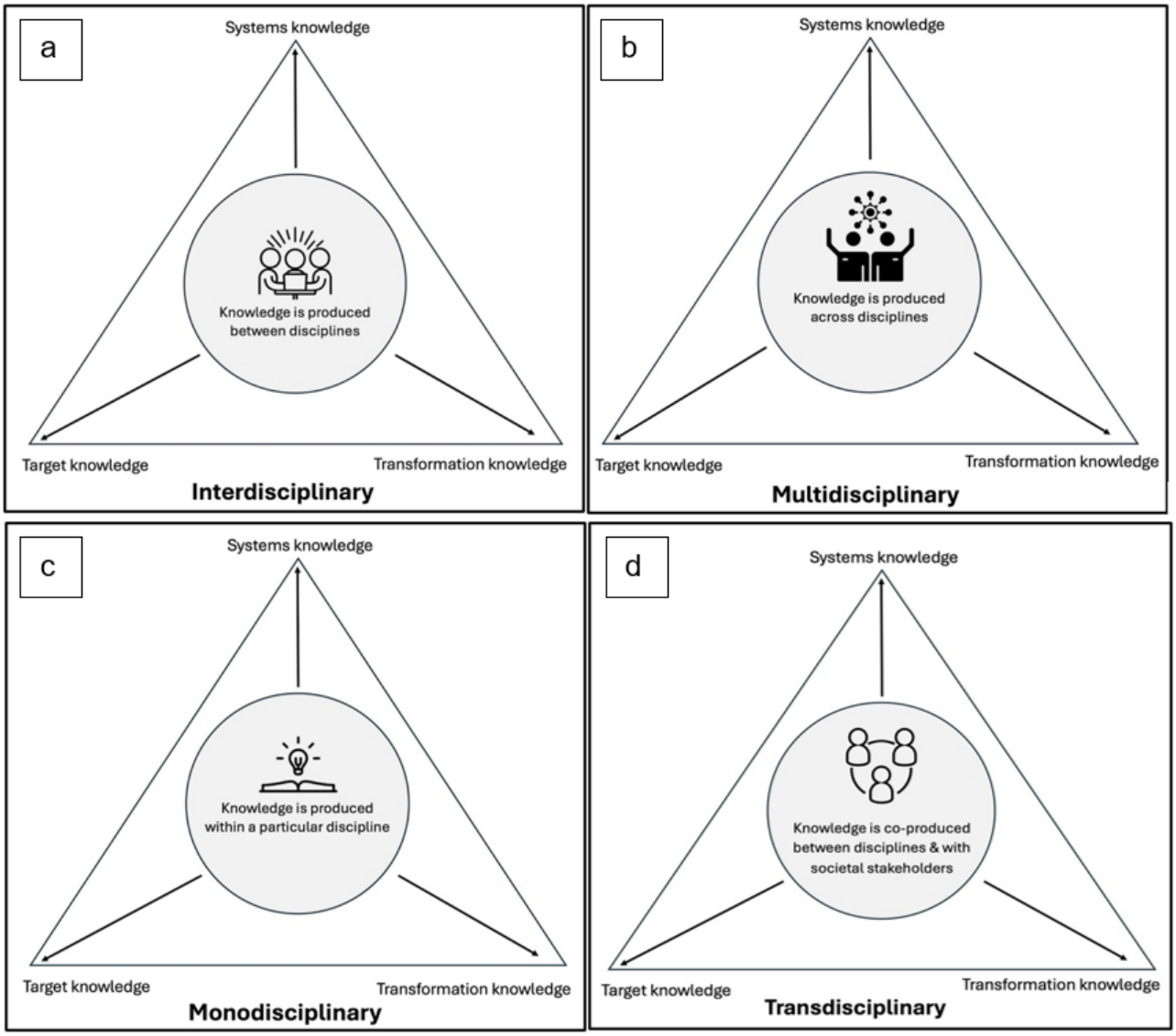

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Figure 1: The process of producing three different kinds of knowledge through the four methodological processes.

Methodological agility and the role of synergetic methods

When working with transformative societal processes, research teams can face two kinds of change: change in real-life situations *and* changes in the understanding of these situations. These transformations are, respectively, associated with ontological complexity and epistemological complexity.[17] Above we highlighted how engaging with JST often involves collaboration with formal and informal stakeholders to co-produce systems, target, and transformation knowledge. In our experience, a certain nimbleness *during* the research process can help one to navigate the emerging complexities and open up opportunities for the co-generation of epistemologically diverse knowledge systems.

By nature, methodological flexibility is seldom planned. Rather, appropriate methods are applied in response to contextual changes as they arise. However, this does not imply that 'anything goes'[18] or that known methods are abandoned. On the contrary, specific methodologies (processes, principles and methods) tend to be associated with certain research processes. For example, when a transdisciplinary approach is adopted in JST-related research, certain synergic methods become useful. In synergic approaches, mixed-methods are used synergistically to respond to the specific needs of the project and to explore the complex issue at hand. In using the term 'synergic', we are referencing the concept of 'synergic satisfiers' as defined in *Human Scale Development*, where, in the discussion on 'Needs, Satisfiers and Economic Goods', the author Max-Neef explains that synergic satisfiers serve to "satisfy a given need, simultaneously stimulating and contributing to the fulfilment of other needs"[19]. A good example here is that of a mother breastfeeding her baby, thus satisfying the baby's needs for *subsistence, affection and security* at the same time with the single act of breastfeeding. While many methods can be applied in an agile or synergistic manner, thick mapping is an integrated approach that can enable research teams to create multi-layered representations of complex real-life situations.

Thick mapping: Layering diverse data

Using innovative combinations of qualitative and quantitative methods, research teams can apply this tool to build rich depictions of current *and* future states of specific problem situations.[20,21] The two-fold aim behind thick mapping is to (1) better understand the intricacies involved in determining the current state of an issue and (2) facilitate informed decision-making to help shape possible future states. For example, when working on JST challenges, systems knowledge can be co-produced by using a wide variety of quantitative methods for capturing detailed aspects of the infrastructural, technological, and ecological systems contributing to the unsustainability of the current situation. In 2022, Carvalhaes and

colleagues[22] published a study on Hurricane Maria in Puerto Rico, where thick mapping was leveraged by combining ethnographic and geospatial methods. For example, different layers of data were layered and aggregated against ethnographic information to explore resilience capabilities in relation to the extreme weather event at hand (hurricane). Through this process, the authors gained insight into how affected individuals made sense of their lived experiences of Hurricane Maria and how this knowledge was embedded in institutional, ecological, and infrastructural systems.

Thick mapping methods

In Supplementary table 1, we share a list of tools that research teams can apply to create thick maps. Different methods and various combinations of these tools can be applied by teams to meet the project context. However, this list is not a definitive list for JST-related research. New methods are constantly being developed and applied to advance this field. Here we list three examples of innovative tools which are being applied in explorative JST studies: virtual reality, participatory and bioacoustics methods.

Virtual reality tools: Virtual reality approaches are emerging as popular research tools when tackling complex societal transformations.[23,24] For example, virtual reality tools can enable research participants to (re) imagine more 'just' and 'sustainable' future states (target knowledge), and also devise multiple transitioning pathways (transformation knowledge). This process can help initiate the development of more desirable future states, as participants can explore *adjacent possibilities*, which can be situated *within* the current situation, or in a significantly different space *from* their context. A practical example of this approach was the first author's use of virtual reality approaches to engage participants in the co-design and co-construction of the iShack in the informal settlement of Enkanini, which lies in the town of Stellenbosch in South Africa.[25]

Digital storytelling and participatory research: Because JST research seeks to advance epistemic justice, digital storytelling, which is a participatory visual method, is relevant here. Digital storytelling is a well-established research approach that can enable the involvement of non-academic stakeholders in the research process and to influence policy.[26,27] Moreover, as a narrative-based tool, it can enable stakeholders to generate data by drawing on their lived experiences of a specific issue.[28] For example, in an ongoing project, the second author, Treffry-Goatley, is collaborating with citizens from four resource-poor settings of sub-Saharan Africa to create digital stories about the impact of extreme weather events on mental health. These narrative data will be created in participatory research workshops held at each site and will be layered with various quantitative data sources, including health outcomes, statistical analyses of survey data, and weather monitoring reports to build evidence and to devise effective strategies.

Bioacoustics: While PR can help to include marginal human voices in JST research, bioacoustics has been used in a variety of contexts to record the 'voices' of non-human actors, including fauna and flora.[29] Indeed, in a recent article in *Nature Communications*, Müller and colleagues[30] noted that numerous "taxonomic groups, including amphibians, birds, mammals, and insects include a considerable proportion of species that vocalize or otherwise use sound to communicate, making acoustic monitoring of these groups a particularly promising tool for biodiversity responses". For example, during times of drought, trees produce specific sounds. This discovery could assist scientists in determining when trees are drought-stricken and require urgent watering.[31]

Ethical considerations when using thick mapping

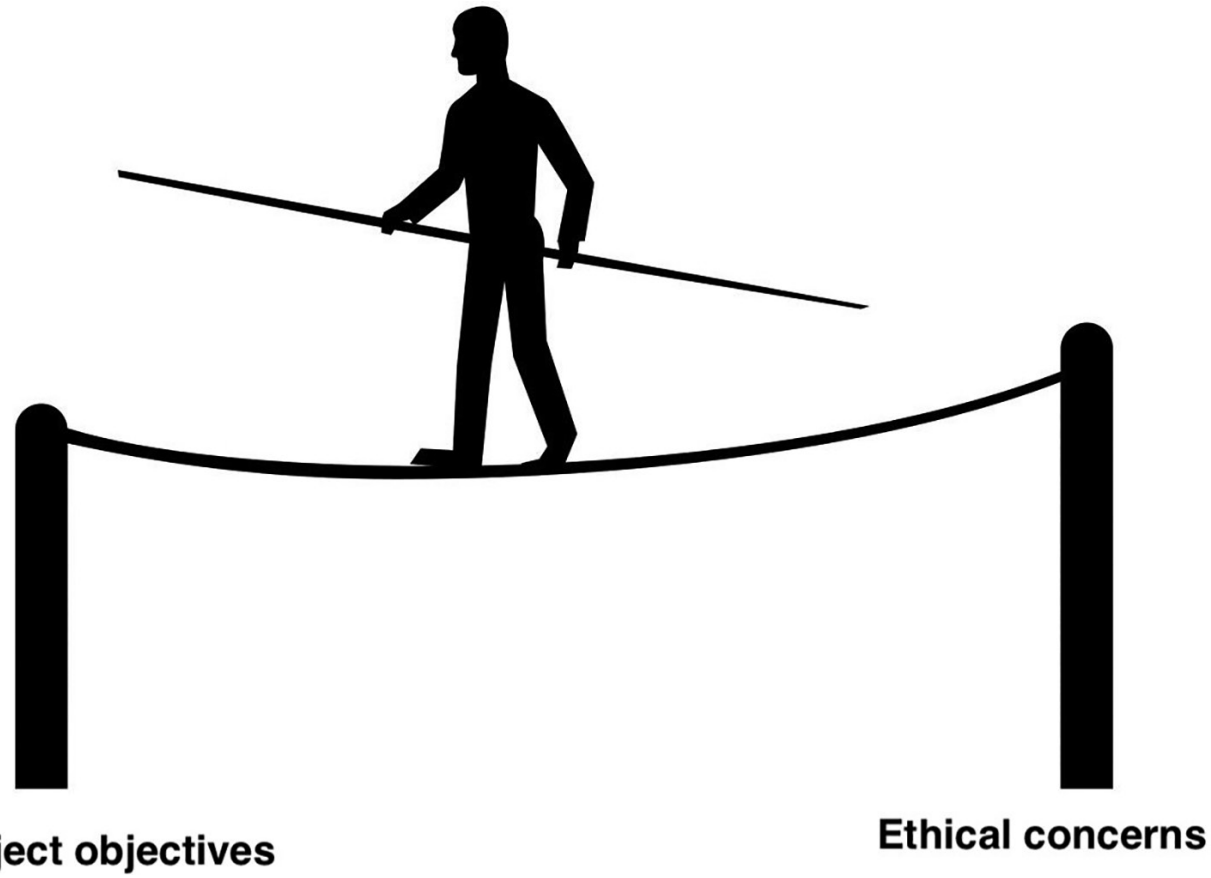
Deciding what data should be included is one of the key ethical challenges of co-constructing thick maps. Indeed, the risk of excluding marginalised perspectives from thick maps is a significant ethical issue for research teams to consider. To navigate this challenge, we recommend the application of the 'foregrounding and backgrounding' approach[32], in which data are moved between the 'background' or 'foreground' as and when needed. While one needs to still pay attention to which voices are 'foregrounded' or 'backgrounded', importantly, data are never permanently excluded or included. On the contrary, the data are saved to be used in response to emerging contexts and issues. Moreover, specific 'voices' and data can be highlighted where needed. This approach can help one to navigate the complexity of JST processes as it allows all JST pathways to be treated as equiprobable and adjacent possibilities.[33,34] This approach can also allow one to build layers of data. For example, one can add qualitative layers to quantitative systems knowledge to foster a deeper understanding of the complexities and contradictions of the current anthropogenic crisis. This can be achieved by, for example, using narrative-based methods for capturing peoples' lived experiences, as narratives, of any unjust social and institutional arrangements contributing to the inequalities of the current situation (see the example relating to Hurricane Maria above).

In addition to the general ethical challenges which are associated with thick mapping, each of the innovative tools outlined above also has its own inherent ethical considerations that need to be addressed. Ethical issues associated with participatory visual research, including digital storytelling, are discussed by Black and colleagues[35]. Additionally, ethical challenges can arise in the application of virtual reality research approaches. Indeed, while virtual reality can offer interested stakeholder groups safe (virtual) spaces to meet and explore present and future possibilities, learning how to move between real and virtual spaces amid research processes can be a challenge. The agility needed for this is depicted by the fleet-footedness of the mythical Hermes figure in Figure 2, who was known to deliver messages from the gods to the people, and vice versa.

It is important to remember, when switching between these co-created virtual and real places and spaces, that Hermes was not a 'neutral' messenger. Rather, according to legend, he was also known to be a trickster, who employed unethical and deceitful tactics during his 'mediating' work.[36,37] Certainly, when employing virtual reality tools (and any other method), one needs to always remain conscious of ethical concerns and critically transparent about the (potential) risks involved. Like tightrope walking (Figure 3) employing these innovative tools requires careful practice. One needs to learn how to maintain a balance between advancing the project objectives and safeguarding the well-being of participants. It is essential to always work within the agreed-upon ethical principles and practices and adopt an inclusive logic, as articulated in the notion of the *included middle.*[38,39] Nonetheless, ascertaining how to achieve this balance, while engaged in complex JST processes, remains one of the biggest challenges in developing methodological agility.

Source: Original image created by the authors using Microsoft PowerPoint.

Figure 2: Oscillating between virtual and real worlds.



Source: Original image created by combining text with a royalty-free image obtained from https://thenounproject.com/. Credit: LeftHandedGraphic (reproduced under a CC BY 3.0 licence).

Figure 3: 'Tightrope walking' between ethical concerns and project objectives.

Conclusion

Advancing JST in the context of the prevailing legitimation crisis and the Anthropocene may be complex, but it is not an intractable challenge. In this piece, we suggest that methodological agility can help scholars to respond constructively to this challenge. In summary, this requires research teams to learn where, when, and how to:

- adopt mono-, multi-, inter-, and trans-disciplinary methodologies;
- co-produce systems, target, and transformation knowledge, using synergic methods;
- apply quantitative and qualitative methods to co-construct thick maps; and
- explore real vs virtual domains to create co-designed safe spaces to (re)imagine more 'just' and 'sustainable' futures.

Methodological agility is an ontological learning process embedded in contextual conditions. There are no shortcuts. Yet we have recommended tools that can assist researchers to successfully navigate this process. We have focused on the benefits of using thick mapping and have unpacked three methods that can be incorporated into this mixed-methods approach. Additional methods that we recommend for thick mapping are listed in Supplementary table 1. Nonetheless, there will be many more ways and means that are not referenced in this paper. This list will expand as new tools emerge in response to technological advances and shifting contextual conditions. We encourage readers to reach out to us with research approaches and experiences and to join us on our learning journey. Additionally, we emphasise the need to remain critically aware of any ethical concerns that arise in research. Failing to maintain this ethical focus can undermine the credibility of the scientific project and further the legitimation crisis.

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Declarations

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Funding impact: The landscape for transdisciplinary sustainability science support

Significance:

A key challenge facing those interested in developing sustainability science engagement and engaged sustainability science approaches is identifying relevant sources of funding for transdisciplinary forms of science that involve multi-actors in the scientific knowledge generation process. This Commentary provides an overview of progress made in the international research funding sector towards support for such research through large-scale granting mechanisms, and points to some challenges that remain.

The concept of transdisciplinarity, which emerged in the 1970s and 1980s, was originally made popular in the fields of science studies, philosophy and systems thinking by, amongst others, French philosopher Jean Piaget and theoretical physicist Basarb Nicolescu. Since then, transdisciplinarity has steadily gained traction in fields such as global environmental change and public health, and is today advocated most prominently in the broader domain of sustainability science.[1] It is in this broad domain that transdisciplinarity was explicitly picked up by research funders, at national and international levels, and made central to many of their funding schemes.

Belmont Forum

Interestingly, the promotion of transdisciplinarity as a funding criterion accompanied a move towards multilateral funding for global change and sustainability research. The historical roots of this date back to 1990 with the establishment of the International Group of Funding Agencies for Global Change Research (IGFA).[2] The IGFA was an informal group consisting of representatives from 21 national research agencies, including South Africa's National Research Foundation (NRF), and the European Union. The IGFA met annually to share best practices and emergent trends, and to encourage commitments in promoting interdisciplinary global change research, including support for the work of the four major international global change research programmes in existence at the time. The latter included the World Climate Research Programme (WCRP), established in 1980; the International Geosphere Biosphere Programme (IGBP), established in 1986; the Diversitas programme on biodiversity science, established in 1991; and the International Human Dimensions of Global Environmental Change Programme (IHDP), established in 1996.

IGFA had no decision-making authority and collective or joint funding was not possible at that stage. Each agency independently pursued their own global change initiatives, but in a manner informed by the work of fellow agencies. Multilateral collaboration between those agencies was realised only to the extent that each provided support to the international programmes mentioned above.

Two important processes – both essentially aimed at amplifying and accelerating the impact of global change and sustainability research, and both adopting transdisciplinarity as a pathway to impact – were initiated in 2009: the establishment of the Belmont Forum and of Future Earth. The Belmont Forum process was led by the National Science Foundation (US) and the Natural Environmental Research Council (UK), which hosted a meeting of selected environmental and geoscience funding agencies at the Belmont Conference Centre in Maryland, USA. The group agreed to collaborate as a forum committed to jointly funding and supporting "international transdisciplinary research providing knowledge for understanding, mitigating, and adapting to global environmental change". This intention was realised when the Belmont Forum's first Collaborative Research Action (CRA) on Coastal Vulnerability and Freshwater Security was launched in 2013. The Forum's latest call, developed under the leadership of South Africa's National Research Foundation, focuses on supporting African research collaboration in three priority themes: the water-energy-food-health nexus; pollution; and disaster preparedness, responsiveness and recovery (https://belmontforum.org/cras#arc).

The Belmont Forum served as the Council of Principals for IGFA until 2014 when the two bodies formally merged under the banner of the Belmont Forum[3] and with a jointly appointed permanent secretariat put in place by 2015. Since its inception, the Belmont Forum has launched 21 calls for proposals from an international research audience and funded 155 projects. More than 1000 scientists and stakeholders from over 90 countries have participated and benefitted from the Belmont Forum collaborative actions. The themes addressed to date include food security, climate predictability and inter-regional linkages, biodiversity and ecosystem services, Arctic observation and science for sustainability, and mountains as sentinels of change. On average, the Belmont Forum has committed UDS12.5 million per annum over the period 2013–2022 to transdisciplinary and collaborative global change research (Arbour N, 2024, written communication, May 02). One of the Belmont Forum CRAs focused on the theme of transformations to sustainability.[4] This represented a second phase of an international funding programme that the International Social Science Council launched, with support from Sida[5], the Swedish development cooperation agency, in 2014. Phase one of the T2S programme funded 38 seed grants and three major international projects called Transformative Knowledge Networks (TKNs). In the second phase, the Council, again with the support of Sida, combined forces with the Belmont Forum and a network of European agencies focused on support for the social and human sciences (NORFACE[6]) to jointly fund 12 TKNs.

The T2S programme demonstrated the multiplier effect of the partnerships that the Belmont Forum was able to convene. It also provided the Forum with an approach to increasing participation of scientists from Global South countries that do not hold Belmont Forum membership; this participation was enabled by Sida funding.

Regarding participation of scientists from Africa in Belmont Forum collaborative actions, there are currently only three funders representing the continent in the Forum's membership. They include South Africa's NRF; the Fonds pour la science, la technologie et l'innovation (FONSTI), Côte D'Ivoire ; and the National Research Foundation of Kenya. Despite this, earmarked resources provided by some Belmont Forum members (e.g. the Research Council of Norway) and partners like Sida, as well as the US-based organisation known as START (Global Change SysTem for Analysis, Research & Training[7]), have ensured African participation in at least 10 Belmont Forum CRAs. Since 2013, funding available for African researchers from the Forum has amounted to approximately USD6.3 million, of which USD1.6 million came from African funding agencies and USD4.7 million from Belmont Forum partners. Across all CRAs to date, 57 African institutions from 22 African countries have been involved in Belmont-funded research. African participation in Belmont Forum initiatives is still restricted. However, recent developments in the Science Granting Councils Initiative[8], aimed at growing active national science granting agencies across Africa, will hopefully broaden this participation in international co-funded Belmont Forum-like initiatives from the continent. Impact reviews of Belmont Forum funding to date are available online.[9]

Future Earth

The second important process initiated in 2009 involved the merger of the IGBP, IHDP and Diversitas global environmental change programmes into what became Future Earth[10], an international sustainability science research network formally launched during the Rio+20 Summit in 2012. Future Earth supports 27 Global Research Networks, all intended to generate inter- and transdisciplinary research at the forefront of sustainability science. With support from national funding agencies and via external fundraising, Future Earth provides limited grants (typically about EUR50 000) to support international travel, as well as diversity objectives including early career development activities. The impact of Future Earth is summarised in its comprehensive series of annual reports.[11]

Alongside international bodies like the International Science Council (ISC) (and its predecessor organisations, the International Council for Science and International Social Science Council), Future Earth became a partner of the Belmont Forum. In this way, the Forum convened a powerful international group of sustainability science funders, researchers and advocates, all working together to advance transdisciplinary research.

A Future Earth Africa Hub, hosted by the NRF, and including a Leadership Centre that is co-led by the Universities of Rhodes and Pretoria, was launched in 2023. The Leadership Centre will serve to support transdisciplinary sustainability science on the African continent through the development of science clusters, the nurturing of young emerging scientists and, ultimately, the establishment of an African Sustainability Science Association.

International Science Council

The ISC was established in 2018 following a merger of the International Council for Science and the International Social Science Council. Both these predecessor organisations had a long history of supporting international global environmental change research, a function that has been taken forward by the ISC with a focus on transdisciplinary sustainability science.

In 2019, the ISC led the convening of a first meeting of what was called a Global Forum of Funders (GFF).[12] This marked a further significant move towards support for international transdisciplinary sustainability science research. The 2019 event was hosted by the National Academies in Washington DC, and brought together leading representatives of national funding agencies (including Belmont Forum and Global Research Council members), development cooperation agencies, as well as philanthropic foundations. The purpose was to explore pathways to fast-tracking the global response to Agenda 2030 by means of increased levels of ambition in cross-sectoral and multilateral funding. The GFF, which met again in 2021, requested the ISC to propose a mechanism to achieve more rapid global SDG progress. In 2021, the ISC published a landmark report, *Unleashing Science: Delivering Missions for Sustainability.*[1] The report highlighted a number of salient points for more rapidly achieving a sustainable future, including:

(i) the urgency for meaningful interventions to fast-track the delivery of the SDGs at scale and with impact;

(ii) that the funding base for transformative sustainability science must be scaled up to a point where the science can meaningfully engage with society and that is proportionate to its attempts to address some of the most pressing problems faced by humanity, including climate change, inequality, food-, water- and energy security;

(iii) that the prevailing science-guided sustainability change agenda is faltering for a variety of reasons, including lack of credibility, trust, and political and societal buy-in as well as nefarious profit-seeking agendas;

(iv) that science needs to change the way in which it engages society, ensuring that it works with rather than for society (this is required to build trust and find traction for meaningful societal transformation in pursuit of sustainability);

(v) the most appropriate research approach for achieving these objectives is an honest transdisciplinary research agenda that is deeply committed to the principles of co-design, co-production and co-implementation[1].

In response to the *Unleashing Science* report, the ISC convened the Global Commission on Science Missions for Sustainability in December 2021, and tasked a Technical Advisory Group to provide an implementation pathway for Science Missions. The Technical Advisory Group's recommendations, *A Model for Implementing Mission Science for Sustainability*[13], were summarised in a consensus Commission report, *Flipping the Science Model*[14], in 2023.

The ISC Science Missions initiative is ambitious; it is targeting the establishment of up to 20 Science Missions around the globe, with an emphasis on regions which are lagging most in achieving the SDGs. The ISC is targeting an annual budget of ~USD1 billion for the entire network of 20 Missions, over an initial 10-year period. This would place the ISC Science Missions initiative at a similar scale of funding to the global CGIAR network[15] with its particular focus on promoting food security and the green revolution.

To achieve the targeted USD1 billion/annum investment in trans-disciplinary sustainability science will require collective commitments from national and private research funders and foundations and private sector partners. Despite this ambitious funding target, a sum of USD1 billion/annum would represent less than 1.5% of the annual budgets available to the Global Forum of Funders alone, and less than 0.5% of the global annual R&D spend. This seems to be a minimal investment in an attempt to rescue Agenda 2030 and secure a sustainable and dignified future for humanity. The remaining 98% of research funding is either distributed nationally or allocated to shared large science infrastructure projects. However, should these efforts by the ISC succeed, it would represent an unprecedented commitment to support broad-ranging multilateral scientific cooperation in pursuit of Agenda 2030. The further development of multilateral sustainability science funding mechanisms, complementary to ongoing national funding commitments, is essential for achieving the SDGs, as no single nation state or region will achieve a sustainable future on its own.

To start this ambitious initiative, the ISC recently called for pilot proposals to establish demonstration Science Missions for Sustainability[16] and to generate appropriate funding support. The launch of the selected pilots is anticipated for 2025.

With key developments in the international funding landscape, such as the ones described above, support for transdisciplinarity as a pathway to sustainability research impact has come into its own. However, what has also become clear during the development of transdisciplinary research over the last decades, is that the successful execution of transdisciplinary research projects requires a critical mass of core competencies that are not easily entrenched in traditional disciplinary academic structures. A mix of stakeholder engagement, participatory methods, data intensive

scenario development, collaborative project management, monitoring and implementation, and multidisciplinary researcher participation skills, is what the ISC Science Missions for Sustainability call is attempting to create.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. Authorship was determined alphabetically. Both authors read and approved the final version.

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Is our skills system ready for a sustainability transition?

Significance:

Skills are seen as crucial to support a just transition away from a carbon-based economy, both to develop the expertise required for the transition, and to prepare people who work in carbon-heavy jobs for jobs in new and emerging occupations. This Commentary provides an overview of research findings to explore the ways in which our skills system is ready, where it is lacking, and why skills can be only a small part of ensuring a just transition.

Transitioning away from a carbon-based economy in ways that are socially just and that support social development is a complex problem. Expertise is crucial to ensure that this transition can happen – that the country has the expertise to develop technological solutions in ways that work for society. Policymakers hope that 'skills' will ensure that the transition is just, in the sense that people who work in carbon-heavy jobs can get jobs in new and emerging occupations and sectors of the economy.[1] Is our skills system up to the job?

The answer is, 'yes', 'no', and 'it's complicated'.

Yes, because there is much activity around curricula, particularly in higher education and private education institutions, with short courses focused on specific issues in the spotlight for the transition.

But also no, because our skills system is clumsy, both in terms of how we obtain insight into employers' short-term skills needs, and how we provide funding to support urgent short-term training programmes. A key problem here is that our systems do not disaggregate sufficiently between immediate skills needs and building expertise for the medium to long term. They also work against coherent steering from the state in priority areas.

The answer is complicated for a number of reasons, but one reason is that, in the main, we do not have, and are unlikely to be able to obtain, sufficient clarity on emerging skills needs to enable substantial responses from educational institutions beyond short course provision.

This Commentary synthesises findings from research projects conducted at the Centre for Researching Education and Labour, work in policy processes, and analyses of the international literature on skill formation systems, to expand on these three points, followed by a brief reflection on what could be done.[2-6]

What are 'skills'? Inevitable tensions in educational preparation for work

A major reason that our system is not ready to support the skills needs of a just transition is the confusion between short-term specific training, and medium- to long-term foundational education. This confusion is also one of the reasons we have weak insight into employers' needs for skills, as well as poor mechanisms for funding just-in-time training.[3,7]

Part of this confusion has to do with the word 'skills' and how it is understood. The term is sometimes seen as referring to limited practical skills, but in other cases it is used as shorthand for qualifications and broad expertise. Research literature on educational preparation for work emphasises that, other than very specific manual skills, even specific and narrow 'skills' are embedded in complex ways in bodies of theory – what philosopher Christopher Winch calls applied practical knowledge.[8] Because of this, there is always a tension in how broad and how specific the programme should be when designing any educational programme that aims to prepare people for work. This is a tension that is never completely solvable.

The data that our skills anticipation system obtain from employers (discussed further in the next section) have many weaknesses.[3,7] But to the extent that the data are an accurate reflection of skills needs in the economy, they reflect the skills that employers need in the immediate, short term. But the systems that are used to plan provision – particularly the programme and qualification mix of our technical and vocational education and training colleges and universities – are focused on the medium to long term. This is because it takes time to design a curriculum; enrol students; and to teach, assess, and graduate students. There are also simple constraints of time – of what can be packed into a curriculum – and prior knowledge of students, that shape what can and cannot be taught. These issues come starkly into perspective in South Africa's college system, where the intake tends to be students with very weak prior educational achievement.

It also does not make sense to provide educational programmes for specific jobs, particularly where jobs are changing fast, and it is in any case impossible for education and training institutions to do so with any substantive offering. Formal education by its nature is aimed at foundational learning that can form the basis for a range of different possible occupations, or training for a specific occupation (see Shalem and Allais[9] for an elaboration).

Educational programmes focus on theory and foundational learning because this is what formal education can and should provide. Foundational knowledge and expertise underpins and supports short-term practical training. But this is also what makes workplaces and individual learners impatient with formal programmes – because much of the theory is not directly or visibly relevant. Training that is specific to a particular work process or job is best learnt in workplaces or through educational institutions that are funded to work directly with workplaces in planning and conducting such training. Yet, our skills anticipation systems make it difficult to obtain such funding, because of rigid accreditation requirements and 'funding windows' of the sectoral education and training authorities (SETAs)[7].

Some of the ways in which we are not ready

A rapidly changing world requires fast input from employers into their skills needs. In theory, we should be able to access these data on an annual basis. We have specific institutions, rules, and tools that were designed to understand the specific skills needs of employers in different industries, and to encourage and support them to train.

This system is sometimes referred to as the skills levy system.[10-12] It works like this: employers with an annual payroll exceeding ZAR500 000 pay a levy allocated via the tax system to SETAs. The SETAs return 20% of the money when employers submit an annual workplace skills plan and training report. The intention is that these documents provide insight into employers' skills needs as well as reporting on where training is taking place. The remainder of the funds (after some are allocated for administrative expenses and given to the National Skills Fund to fund the training of unemployed people) is made available for training that is not already provided by employers. Employers and training providers can bid for money from the SETAs.

But the data obtained from employers are poor, for a range of reasons. Firstly, many employers do not participate in the system, and treat it as an additional tax. This is partly because the transaction costs are high.[13] No insights are obtained from non-levy-paying members (smaller companies), making the national data incomplete in significant ways.

Further, the ways in which employers get their money back from the SETAs sometimes interfere with data quality. Sometimes, SETAs require training reports to match previous workplace skills plans. This incentivises employers to propose only skills needs for which training can easily be provided.[7]

For the rest of the money which is available for training, SETAs have two main funding mechanisms that are made available each year through their 'Sector Skills Plans' – plans that outline training priorities in each sector. In these plans, they list 'funding windows' against which employers and educational institutions can apply, and bursaries in areas that are seen as important. These are chosen based on the aggregated data obtained from employers, as well as an analysis of labour force trends and other research. Our research shows various ways in which this distorts the data that employers submit[7]: some employers also only list those training programmes that will be funded by SETA; some do not list skills needs where the training is going to be supplied by international providers, because often these providers, which provide well-regarded training valued by employers and often essential for specific machinery in the workplace, are not accredited in the South African quality assurance system. Our quality assurance systems are complex, and there is no reason for international providers to participate in them. A further example is that employers list jobs as scarce even when they are not, because they need to train new employees, and grants (funding windows) are not made available in areas that are not seen as scarce or in high demand. At a company level, our research shows that broad-based black economic empowerment (BBBEE) employment scorecard reporting adds further complexity in terms of perverse incentives for training.[5,7]

So, while in theory we have a built-in system to obtain annual information from employers, which should be useful in ongoing planning for a just transition, in fact we are getting very poor data from employers.

As discussed in the previous section, disbursing money through 'funding windows' for which employers and providers have to apply, and bursaries for which individuals or companies have to apply, has large transaction costs, and makes just-in-time training difficult. It is also a clumsy way for the state to attempt to steer training in identified areas.

Two other significant problems in our skills system probably do not need much elaboration. The first is that South Africa's education system serves a portion of its population well, but the rest get a poor education.[14] This is important because people need a strong foundational basic education in order to be prepared for specific technical training.

This compounds the second problem – that our technical and vocational education and training system is weak in general, and in specific is ill-prepared to provide specific training required to support the needs of a just transition.[6,15]

But there are also ways in which the skills system is ready

Many educational institutions, especially in high education, are actively adapting courses, and beginning to offer a variety of tailored courses, including relevant modules in diplomas and university degrees. A review we conducted across the post-school education system indicates that over 220 courses are offered, covering energy-transition topics, with renewable energy dominating at 62%. A challenge, however, is that much of the energy-transition skills provisioning emphasis is occurring in Gauteng (45%) and the Western Cape (32%). There are few courses offered in areas currently impacted (positively and negatively) by a shift away from fossil fuels, e.g. Mpumalanga and Limpopo (coal mines) and Northern Cape (solar PV expansion).

There is also some activity in the Technical and Vocational Education and Training (TVET) colleges, where 18 (37%) offer some form of energy-transition course or module, with the majority focused on renewable energy, notably through the Electrical Infrastructure Construction certificate, or Solar PV technician and installation. These courses are often done in collaboration and with the support of the Energy and Water SETA.

Short courses dominate the energy-transition course offerings, and, in many cases, they are not formally accredited. This underlines the need for more flexibility in quality assurance requirements, coupled with strong national assessment systems to ensure standards.

Many employers train extensively, and are already providing training on new technologies and work processes, despite the difficulties discussed above.[3,5] But this raises a more negative note: there may not be huge numbers of new jobs created in the process of de-carbonisation, unless there is a concerted effort to build downstream and up-stream manufacturing capacity associated with, for example, wind farms. And it is not clear where the new jobs will be, or how occupations are changing, with a few exceptions such as solar installation and maintenance and electric vehicles.

It's complicated

So, while there is work happening in different kinds of short-term training programmes, there is little certainty about what new occupations will be emerging, and the extent to which they will generate employment, as well as how occupations will change and what that will mean for new areas of expertise.[4]

South Africa has an extensive set of policies, legislation, and visions for a green transition. But implementation to date has been haphazard. It remains unclear what will change, when, and where. For example, green hydrogen is seen as important, and is targeted by the Presidential Climate Commission. Accordingly, much work has been done in the skills system. Extensive research has been done to analyse the skills that would be needed for this potential sector.[16] Eleven new courses are being offered at universities; a Green Hydrogen Research Chair was established at the University of Johannesburg; and a hydrogen course was launched in 2023 for TVET students. But what remains unclear is when and how the green hydrogen sector will become a reality. We may end up training for jobs that will never actually exist.

And because occupations require foundational expertise as well as short-term training, as discussed above, short courses will never be enough to get people from being coal miners to being solar technicians. Finally, while new areas of expertise are certainly emerging, it seems relatively unlikely that these will be in areas that will make it possible to reskill workers who are losing their jobs.

So what should be done?

In the short term, we need greater flexibility for 'just-in-time' training. Some changes have been made through the Economic Recovery and Reconstruction Plan after the COVID-19 pandemic[17], which has created flexibility in sectors that were identified for reconstruction: accreditation requirements were relaxed, and funding was prioritised. The skills chapter of the recently released *Just Energy Transition Investment Plan*

attempts to build on this[1], and the needs of the just transition must be used to create further flexibility, to support employers to train, or to source the training that they need, and to support educational institutions to develop such training.

In the medium to long term, we have to recognise that skills planning is not and cannot be linear, and that there are serious limitations to what can be predicted.[3] Instead, we should be building the capacity of educational institutions and systems, recognising that programmes take time to design and constantly 'reforming' education and training provision undermines education provision by creating policy uncertainty. At its best, education can help people master bodies of conceptual knowledge as well as relationships between bodies of knowledge, nurture learning dispositions, and equip people with required skills and capacities.[18] Education can also support new configurations of expertise. But all of this requires a long-term view, and a focus on building, nurturing, and supporting educational institutions. While we have policies in place to do this, funding systems mitigate against it.[19] Reviewing funding mechanisms requires urgent attention from the state.

Finally, we have to accept that skills can only play a small role in ensuring that a transition happens at all, and that to the extent that it does happen, it is just. Skills will not be a panacea to the lack of justice that many will experience in the transition away from a carbon-based economy.

Declarations

I have no competing interests to declare. I have no AI or LLM use to declare.

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Bringing river health into being with citizen science: River commons co-learning and practice

Human health and well-being are directly and indirectly dependent on the life of river systems. Life in river systems is increasingly dependent on human actions that bring river health into being. Rather than describing river health as thing, problem or management challenge, this paper explores how river health is brought into being, through the citizen science practices of the Amanzi Ethu Nobuntu project in the upper uMngeni catchment in South Africa. The study draws on focal data produced by citizen science practitioners, as interpreted by them in collaboration with partners in the catchment, and their reflections on the meaning(s) of river health and how it came into being. Drawing on the concepts of citizen science as a co-learning process, integrative views of One Health, and commoning as activity, the study offers a rich interpretation on how river health comes into being. The study shows the complex interrelated practices involved, including practices of resolving leaks and pollution challenges, social and community engagement, and the co-learning involved in citizen science practices itself. It offers insight into the social-ecological and ethical-political ontological dynamics of river health commoning activity, thus offering alternatives to reductionist approaches to bringing river health into being, potentially also enriching tools for river health reporting.

Significance:

The significance of the main findings of Sustainability Science Engagement and Engaged Sustainability Sciences includes how citizen science can be key for engaging local communities in sustainability research around sustainability challenges, such as river health, by linking to the health of the people and their everyday engagements with the river. Further contributions include conceptualising sustainability science engagement co-learning processes of being in common around a shared matter of concern, such as bringing river health into being beyond technical specifications. Contributions are also made by highlighting how sustainability science engagement can result in richness in terms of knowing sustainability challenges.

Introduction

Human health and well-being are directly and indirectly dependent on the life of river systems. Life in river systems is increasingly dependent on human actions that bring river health into being. Human health is affected by the health of the rivers and waterways. Rivers are critical not only to human survival but also to human flourishing. From obtaining water for drinking and irrigating crops, we may fish, harvest reeds, have picnics on the river banks or perform cultural and heritage practices.[1,2] Rivers and their wider catchments have a long history of supporting the social and economic needs of people, other living beings and the biodiversity found in rivers. Today, rivers are degrading, as are catchments and their health, affecting river health and human health. As said by Giordano[3]:

> *Degrading water quality can not only infringe upon human health, economic well-being, and the environment but can also effectively reduce the overall availability of the resource itself, integrally linking this particular element of the water resource equation to the more commonly emphasized supply and allocation components.* (p. 112).

Context-specific social and biophysical drivers of catchment degradation and loss of river health quality are interlinked.[4] Health and sustainability challenges are exacerbated by catchment degradation and poor water quality management, resulting in the spread of multi-resistant *Escherichia coli* and cholera infections.[1] One of the challenges in multiple South African catchments is the failure of wastewater treatment works (WWTWs), resulting in raw sewerage leaking into rivers. Wastewater treatment works are experiencing "system failures due to ageing systems and pressure on deteriorating facilities, resulting in raw wastewater discharges into catchments"[4]. This is coupled with pressure on systems due to increasing service demand, poor operation and maintenance and lack of well-trained personnel.[5-7]

According to the Green Drop report[7], only 1% of wastewater treatment works scored the required 90% on the eight compliance water treatment factors. It was found that 65.8% of wastewater treatment works are at a high to critical risk to the environment around them.

As an emerging sustainability challenge in Southern Africa and beyond, rivers and their health are part of discussions on the commons (i.e. rivers as part of the common well-being of people and planet).[7-10] Sweeney and Blaine[11] state that:

> *River systems are the world's ultimate commons. Their waters, which are essential to all life, provide food, water for drinking and bathing, transportation, irrigation, and hydropower. They also have been used throughout human history to carry off our waste, transporting our household, agricultural, and industrial effluents downstream. If we do not overload them, streams and rivers are capable of processing the pollutants we discharge into them while continuing to provide food, clean water, and habitat for wildlife.* (p. 755)

Like Sweeney and Blaine's US analysis, South Africa has overloaded its river systems dangerously: the most recent assessment by the South African Department of Water and Sanitation (DWS)[2] of 364 sites spread across the country, using the South African Scoring System Version 5 (SASS5) method, found that:

> *Approximately 50% of the sites were in a moderately modified (C category) condition. Few sites (16%) are in AB, B or BC categories* [meaning good condition]. *These sites are mostly located in the upper reaches of the catchments. Only the Vaal River WMA had no sites in a good (better than C category) condition. Approximately 5% of the sites are in an unsustainable (DE to E) condition, generally located in urban areas and subjected to modified flows and habitat alteration in addition to pollution.* (p. 2, our emphasis)

According to the DWS, "upper reaches of rivers tend to be in a better condition, with the state of the rivers deteriorating downstream"[2(p.2)]. However, the South African National Biodiversity Institute's National Biodiversity Assessment[12] indicates that national monitoring data for river and inland wetland systems are incomplete and insufficient to show trends in ecological condition – an issue which DWS recognises. SANBI assessed the state of the rivers as[12]:

> *River ecosystem condition declined by 11% between 1999 and 2011. Of the 222 river ecosystem types assessed, 64% were found to be threatened (43% Critically Endangered, 19% Endangered and 2% Vulnerable). River ecosystem types are also Poorly Protected with only 13% considered Well Protected and 42% Not Protected. The majority of rivers (67% of total river length) are degraded. Tributaries are generally less heavily impacted than main rivers with 38% of tributary length in natural condition compared to 28% of mainstems. The percentage of threatened river ecosystem types is higher for lowland and lower foothill rivers (67%) than for the upper foothills and mountain streams (25%), which is a reflection of multiple pressures accumulating and increasing from river source to sea.* (p. 90)

This shows the dire situation in understanding river health, with the SANBI National Biodiversity Assessment commenting on the "generally poor ecological condition of South Africa's rivers, as two-thirds of the total length of rivers is degraded"[12(p.17)]. Solutions proposed are co-operative governance and cross-sectoral governance and planning, increasing flows to degraded rivers, improved assessment, planning and monitoring, and practical action such as removal of alien invasives to increase flows to degraded rivers, and waste and pollution management, stewardship and education.

Little is said of *how* these and other river commons practices emerge, that is, how river health comes into being. Sweeney and Blaine[11] propose three strategies for resolving river commons concerns: education, legislation and incentivisation, while SANBI recognises that "Cooperative governance, research and citizen science are key elements of inland aquatic ecosystems monitoring"[12(p.94)]. In this paper, we consider mainly the first and aspects of the third approaches proposed by Sweeney and Blaine[11] and SANBI's[12] recognition of citizen sciences. We consider how education implemented via citizen science practice coupled with incentivisation (creation of work for unemployed youth) can contribute to the resolution of river commons concerns, through citizen science practices that can potentially bring river health into being.

The Amanzi Ethu Nobuntu project

The paper explores how river health emerged through citizen science and associated co-learning practices in the Amanzi Ethu Nobuntu (AEN) ['Our Water, Our People'] project led by the Duzi-uMngeni Conservation Trust (DUCT) in the upper uMngeni catchment in South Africa. AEN "came about in 2021, first as the flagship project of the uMngeni Ecological Infrastructure Partnership (UEIP), and later as a legal entity operating as strategic project co-ordination arm of the partnership"[13]. As a networked partnership project, AEN combines citizen science monitoring practices, youth employment and environmental skills development and includes participating organisations mainly in KwaZulu-Natal, South Africa. Building on the 'Enviro-Champs' project, it is informed by the 2002 State of Rivers Report that developed an assessment of the uMngeni river and neighbouring rivers and streams[1] as well as the Ecostatus Monitoring Programme State of Rivers Report 2017–2018[2]. The State of Rivers Report[1] and subsequent assessments show the uMngeni catchment to be rapidly developing with high pressures on water resources, located in a strategic water management area with changing land use, as well as declining water quality affecting supply and quality of water to downstream communities, most notably, the city of eThekwini[14-16], one of South Africa's largest cities.

Most reports on river water quality emphasise ecological and managerial perspectives of river health using water quality tests and catchment system analyses, classifying rivers based on their ability to absorb the effects of human activity and provide goods and services. The 2002 uMngeni State of Rivers Report[1] and the Ecostatus Monitoring Programme State of Rivers Report 2017–2018[2] both segment data based on ecoregions, taking a largely management and expert-oriented stewardship approach. Concerning our interest in how river health comes into being, not much insight is given to how local communities relate to the river and what value these ways of relating bring to them or the river. The report emphasises the importance of education, offering a historical view of the catchment, and noting how cultural and use values are intertwined. The 2002 and 2017–2018 report's emphasis on ecological and managerial dimensions of river health forwards a notion of river health as a referent to being clean, pristine and natural, with similar patterns evident in science-based water quality and catchment assessment reports.[17-19]

Broadly, notions of community engagement, encounters with and uses of the river and people's experiences of what river health means are largely underdeveloped in understandings of how river health comes into being. Most official reporting on river health sees communities either as causes of deteriorating river health or 'stewards'. Conceptualisations of river health are mainly based on externally measured inputs and outputs from the river, that is, what impacts a river system can absorb and the goods and services that a particular river system offers. Not much attention is given to the actual needs and views of local communities in constructing meaning(s) of river health. The river becomes privileged, not the river commons, that is, people's being and becoming *with* rivers, socially, politically and ecologically.[10,20]

Giving time and space for citizen science praxis through co-learning and experiences with rivers, AEN developed the notion that to address the state of South Africa's rivers, it is necessary to work and learn together for the common good by employing and empowering local community citizens to become champions of their river environments, that is, Enviro-Champs.[7,21] Engaging communities (youth working partners), AEN operationalises citizen science tools through supported learning processes, enabling people living with the river daily to engage in monitoring and management practices of the upper uMngeni, and thus contributing to bringing river health into being.[7,21]

Between October 2020 and August 2021, the project, as a pilot by the Department of Science and Innovation and UEIP, with DUCT as implementing agent and funded through the Presidential Employment Stimulus Programme employed 500 youths as Enviro-Champs. These youths were spread among UEIP regional partner NGOs, including GroundTruth, a consultancy organisation supporting advancement of citizen science and development of citizen science tools.[21,22] Twenty graduates were employed and split between a field engagement and fieldwork training team (River Rovers) and a data management and reporting team (Data Detectives). Graduates were supported by secondary teams from partner organisations with capacity-building, data analysis and monitoring from DUCT, GroundTruth and Environmental Learning Research Centre (ELRC) at Rhodes University. Throughout the

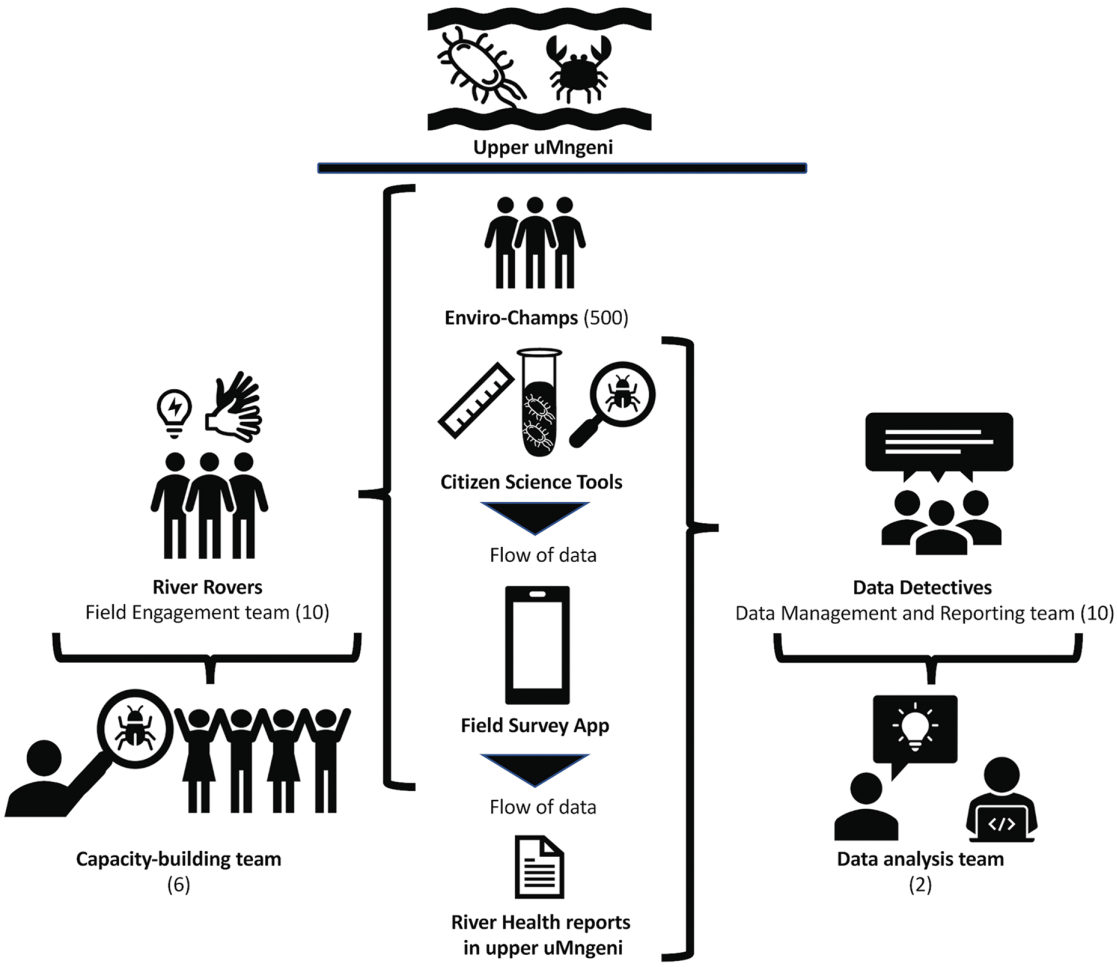

Figure 1: Amanzi Ethu Nobuntu project structure.

project, Enviro-Champs and graduates worked with a custom-designed application (Field Survey App) in capturing monitoring data, which were systematically managed and analysed using documented work plans, resulting in reports as outlined in Figure 1.

Drawing conceptually on a challenge to the universalistic approach to health as detached from context, the paper assumes a praxeological (practice-oriented) approach; the question is not *what river health is* but rather *how a 'healthy' river comes into being through co-learning and practice.*[23-25] We investigated how river commoning practices come into being through knowledge co-creation in addressing health challenges of humans, animals and the environment in the upper uMngeni, supported by citizen science tools. Additionally, our investigation sought to also potentially contribute to novel conceptualisations of river health as shared experiences and relationships, that is, where river commons are privileged. This paper draws on citizen science engagement in this period specifically while forming part of an ongoing expansive social learning research project into the scaling of citizen science praxis in South Africa, in partnership with DUCT and GroundTruth6 through interactions and collaborative learning(s).

Citizen science tools are key components of global water quality efforts, such as the UNEP Global Environment Monitoring System for freshwater[26] and the World Water Quality Alliance[27]. In the South African context, citizen science tools have been used in water quality monitoring of groundwater[28] and aquatic ecosystems and clean-up activities[29] as well as in biodiversity monitoring[30]. Citizen science can occur along a continuum of participation and co-learning, from citizens being used to capture data for scientists (with minimal co-engaged learning) to citizens actively engaging in co-constructing the scientific praxis through co-engaged learning (co-designing tools used, reporting practices and validity of practice).[31] Citizen science tools can also be co-designed, developed, used, refined and redeveloped by scientists in interaction with citizens. The latter characterises the AEN citizen science context, with high levels of commitment to co-learning and improvement of tools via processes of engaged practice and co-learning.[21,32] This provided an analytical vantage point for the study's empirical praxis; that is, we could not interpret it as a 'fixed' or over-determined praxis, but rather as a co-emerging, reflexive practice. In this phase of the AEN, the Field Survey App was piloted and tested (through praxis) as a monitoring and reporting tool, capturing complex datasets from a range of other monitoring tools (e.g. water quality tests) to strengthen systematic reporting in a catchment context.

Methods

The practices we refer to emerged from capturing citizen science-based monitoring data produced mainly by Enviro-Champs supported by River Rovers and through the Field Survey App. This produced a second type of data, involving sense-making and interpretation by the Data Detectives of the incoming data. Designed at the initial stages of the project, data management and analysis plans, co-produced with River Rovers and Data Detectives, guided the analysis process. This produced the empirical foundation of the study, which we continued to engage with via supportive reflective online engagements and contact-based workshops. Subsequent citizen-science practices informed revised plans in an iteratively developed co-learning process.

Figure 2 shows the AEN multidimensional approach to citizen science practice, involving project documents (data management and data analysis plans), citizen science tools (clarity tubes, miniSASS test kits, etc.)[22,33,34] and technologies (health and safety equipment)[21,35]. These tools were activated through in-field training and support for citizen science practices, including miniSASS monitoring activities

Figure 2: Inter-related multidimensional citizen science practices involving diverse actors.

(tests ecological health through indicator species), community engagement and reporting findings through the Field Survey App. Monitoring practices and data co-creation were enacted by Enviro-Champs supported by River Rovers in the upper uMngeni catchment. The data were reflected on collectively by River Rovers, Data Detectives, DUCT, GroundTruth and Environmental Learning Research Centre teams in reflection workshops. Throughout the project, *inter-related multidimensional citizen science practices involving diverse actors* used meaning-making encounters to operationalise, reflect and improve project documentation, technologies and techniques as river health practices emerged, as shown in Figure 2.

Conceptual framework for analysis

The paper utilises a conceptual framework based on citizen science as social learning and agency formation process[21,31,36-38], river commons[10,39,40] and One Health[41-44].

Rivers and their health have emerged as part of discussions on the commons, with calls for moving beyond commons as static resources and towards emerging relationships of 'being in common' with both the social and the ecological.[10,20,40] Lotz-Sisitka[40] draws attention to how Linebaugh[39] shifts commons to the verb, 'commoting'. She articulates how commoning becomes a process of expansive[45], and potentially transformative learning, as people work together to shape commoning practices/activities in response to social-ecological challenges. Linebaugh[39], as cited in Lotz-Sisitka[40], argued that:

> *to speak of the commons as if it were a natural resource is misleading at best and dangerous at worst – the commons is an activity and, if anything, it expresses relationships in society that are inseparable from relations to nature. It might be better to keep the word as a verb, an activity, rather than as a noun, a substantive.* (p. 65)

Lotz-Sisitka further draws on Archer[46] and Bhaskar and Hartwig[47] explaining that commoning processes are influenced by interacting activity-specific generative mechanisms, such as power relations, democratisation processes, shifts in epistemological ownership as enacted in citizen science practices, oriented within learning orientation(s)[31,32]. Commoning, as activity and process, was useful in analysing how river health practices were coming into being via co-learning and contextualising the meaning(s) of river health as people encountered river waters in their local communities and the setting of the upper uMngeni. This also reflects an open process knowledge perspective which "understands information and knowledge systems as operating in an open space composed of multiple and diverse patterns of hybrid social–ecological practices and configurations, inevitably embedded in specific times, spaces and contextual conditions"[48(p.71)].

One Health[42] highlights how the health of life on land and in water is interconnected, with links between human activity, ecological change and health for all[42,43,49]. There is thus a plurality of ways of knowing and addressing river health causes and symptoms as part of an enriched perspective.[44] Health is seen as interconnected with social life, economics and politics, with human health linked to nature. The concept of One Health helped in analytically mapping the social and ecological aspects of river health.[41,44]

We drew on these three concepts in an integrated way, seeking insight into how *'healthy' river comes into being through co-learning and practice*. To limit the scope analytically, we selected 'focal data' from the citizen science monitoring, reporting and reflections that offered insight into the question. This involved analysis of monitoring data submitted via the Field Survey App, shared mainly through Data Detectives' reflections on the data. The Data Detectives produced reports, which they thematically analysed and grouped in terms of different kinds of engagements with river health (e.g. social engagements, technical problems in the form of leaks, waste, river ecologies and working with the fieldwork practice tools). The reports were collectively reflected on online and in contact workshop settings, where understandings and expressions of river health surfaced.

Analysis of focal data

Data Detectives reports

Together with Data Detectives, the reports they compiled were analysed. As indicated earlier, reports were based on river monitoring data generated by River Rovers and Enviro-Champs. Reports focused on river health challenges among communities living with the upper uMngeni (alien clearing, solid waste, sewage and water leaks), social aspects of river health engagement and aspects pertaining to the citizen science learning and practice process (use of field survey app and citizen science tools), respectively. The results of this analysis are outlined in Figure 3 and elaborated below.

First, Data Detectives indicated that understanding and bringing river health into being necessitated contextualisation, expressed as a need for better social data and social engagement capacity for co-creating river health. However, the Field Survey App social data functionality was limited,

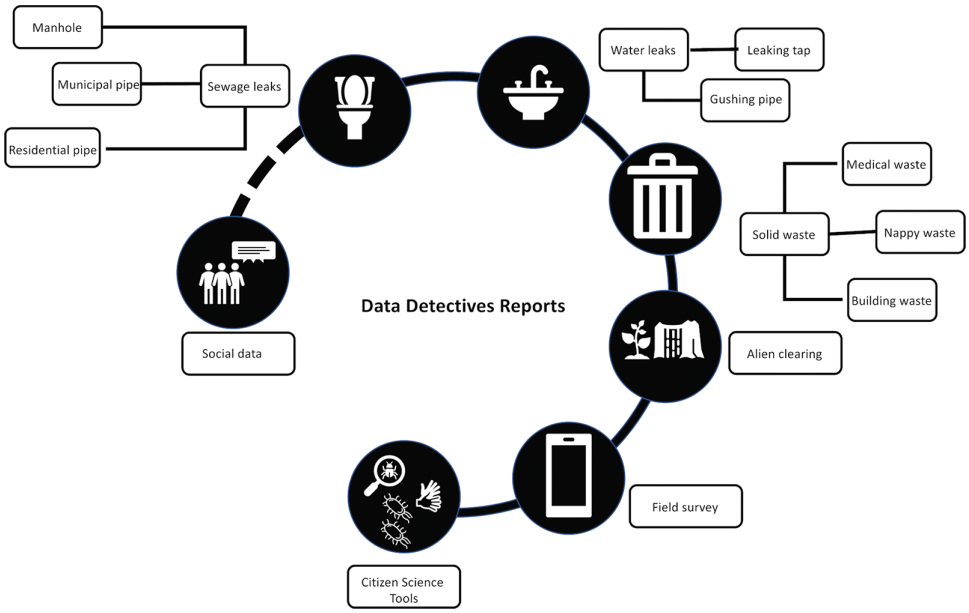

Figure 3: Data Detectives reports showing aspects of bringing river health into being.

Table 1: Reflection sentences offered by River Rovers and Data Detectives in the reflection workshop on what river health is for them

River health in upper uMngeni is for me ...		
...generating data on river characteristics and turning quantitative data into meaningful qualitative data and outputs	...the same state/condition	...an issue that still needs to be looked at or monitored for effective solutions to be made
...see the state or Health of our rivers has been the greatest motivator of the work that I do	...a great initiative towards the promotion of environmental health	...cleaner rivers, more exotic species, a natural state, no pollution, HEALTHY PEOPLE
...means healthy ecosystems	...is shaping the mindset of communities and the youth in ways that are eco-friendly and aware of their behaviour towards the environment	...complex
...the first step towards cleaning and preserving the waters of South Africa	...work in progress	...about seeing a change in the state of *the rivers in a positive way, and it* would be great to have to see our rivers restored and to find stoneflies in all our rivers
...environmental consciousness	...means healthy ecosystems	...in a poor condition through the industrial and communal unsustainable activities. It is also a work in progress numerous partners doing different activities to improve the conditions
...crucial for sustainability	...promoting ecologically literate communities for a sustainable future	...environmentally conscious people taking action, people-centred/ community-centred (not abstract)

hence the dotted line in Figure 3. Second, they indicated that bringing river health into being required giving attention to two kinds of leaks regularly reported on by the River Rovers and Enviro-Champs: (1) sewage leaks from sewer holes, burst municipal pipes and faulty residential pipes; and (2) water leaks from leaking community taps, faulty pipes and pipelines. Third, they identified solid waste in the form of medical waste, disposable diaper waste and building waste as being detrimental to bringing river health into being. Figure 3 shows links between leaks and waste because, sewerage leaks flow directly into rivers in most cases, and water leaks flow through waste carrying contaminants and high levels of nutrients into the rivers prompting the growth of alien invasive plants. According to River Rovers and Data Detectives, bringing river health into being requires river commons rehabilitation practices to arrest alien invasive species that outcompete indigenous vegetation and affect flows and levels of rivers, damaging the river ecosystems and river commons potential.

Reflections on bringing river health into being also focused on the fieldwork by River Rovers and Enviro-Champs in monitoring, reporting and reflecting on river health, which they saw as key to bringing river health into being (hence the flow in Figure 3).

Workshop reflection data

The second focal data analysed were reflections from the May 2022 workshop held at uMngeni Valley. The participatory workshop involved River Rovers and Data Detectives, DUCT staff and members of the GroundTruth and Environmental Learning Research Centre teams. The purpose was to reflect on the 8 months of citizen science learning and practice in the AEN project and to conceptualise activities related to monitoring and reporting. Following individual reflections on how their practices had contributed with value to the AEN project, graduates were paired to share their reflections and jointly address how their practices have contributed river health of the upper uMngeni. From these paired discussions, the participants each articulated a sentence, '*River health in upper uMngeni is for me....'* Eighteen statements were shared on the board by River Rovers and Data Detectives (see Table 1) and formed the basis for a co-created concept of river health in the upper uMngeni, discussed further below.

Table 1 shows the following dynamics of bringing river health into being. The view that river health is a process was prominent. This process was reflected as involving the monitoring practices, as well as engaging communities within a people-centred approach to river commoning. The data also show that bringing river health into being requires healthy ecosystems and the need to move the river from one condition (bad) to another (more favourable) condition. Bringing river health into being also involves restorative practices, co-creating solutions, environmental consciousness / ecological literacy, and advancement of environmental health, healthy ecosystems, healthy people and healthy communities generally.

Discussion and synthesis of the findings

Through the reflective analysis of Data Detective reports (Figure 3), and thematic analysis of the workshop reflection data (Table 1), river health in the upper uMngeni, when enacted via the citizen science co-learning practices, encompasses emergent social-ecological and ethical-political dynamics of bringing river health commoning activity into being as reflected in Figure 4.

The combined social-ecological[48,50-56] and ethical-political[57-61] dynamics of bringing river health into being can be articulated as the ontological foundations of river health commoning activity and its emergence.

River health does not exist separate from the practices of people who are in relationships with the river. River health needs to come into being through the ontological foundations outlined earlier; it is always an emergent relation, enacted through practices of people in time and place with their rivers and the conditions of the rivers. River health is thus a river commoning activity that can be brought into being by citizen science and co-learning in catchments.

As seen in the data and analysis from the AEN citizen science co-learning reflective research, river health commoning activity comes into being in place with rivers, through complex relational practice patterns, involving diverse practices, as shown in Figure 5. Figure 5 illustrates this with the metaphor of an expansive river commoning activity 'flower' of river health emergence in the upper uMngeni. The flower metaphor shows the possibility for flourishing with river health and how it can be brought into being in multidimensional ways, supported by the social-ecological and political-ethical ontological foundational dynamics articulated earlier. River health is thus brought into being along with the health of the people living with and alongside the river as part of the overarching relational concept of One Health in which the ecosystem health of life on land and water is interwoven with human health and activities.

The ontological enactments that brought river health into being from the Data Detectives reports occupy the lower three petals, while the enactments resulting from the workshop analysis are represented in the upper five petals. These enactments bring river health into being through preserving and returning rivers to natural states, and through the creation of healthy ecosystems and healthy people, with the latter ontological enactment potentially in relational tension with the first, as seen in the prevalence of medical waste from human consumption. River health was also brought into being through the practice of critically engaging complexity and developing the citizen science capabilities of communities and youth towards eco-friendly practices. The potential for bringing river health into being through such ontological enactments is expanded by experiential encounters constituted through the multi-layered iterative engagements as outlined in Figure 3, where diverse actors were involved in mobilising and using citizen science tools in a reflexive co-learning approach. This resonates with the concept of river health futures as involving a concept of collective and co-engaged learning with social-ecological ontologies in relation.[10,20]

Our research shows how river health commoning activity can emerge through ontological enactments in citizen science co-learning practices where an open system view of knowledge and contextualised meaning-making is the norm rather than the exception.[48] The commoning activity of river health as part of the AEN project emerged as an open-ended co-creation process where the 'health' of the river emerged through citizen science and associated co-learning practices conducted in the upper uMngeni. River health was brought into being beyond the waters, following citizen science practices, coming to encompass leaking pipes, solid waste, alien invasive vegetation, community engagement, water and sanitation infrastructure, and the co-learning and practice involved in using citizen science tools.

Conclusion

We started this paper with an observation that reports of ongoing deterioration of river health tend to focus more on technical information and data on the state of the river. We recognise these as being crucial for an understanding of river health. However, we sought to enrich and broaden how river health is reported on and understood. We worked with the question of how river health is brought into being through citizen science and co-learning processes in the upper uMngeni catchment, where citizen science innovation is taking place in the AEN project involving young people who were employed as River Rovers, Data Detectives and Enviro-Champs.

Through collaborative analysis, we showed that exploring how to bring river health into being offers an ontologically rich perspective on river health, involving social-ecological as well as political-ethical ontological dynamics, and inter-related multidimensional practices that are non-exhaustive in nature. The analysis shows that citizen science tools and practices, when mobilised in co-engaged ways where co-learning is also valued, can bring river health into being and also help in articulating what river health might mean in our communities and catchments.

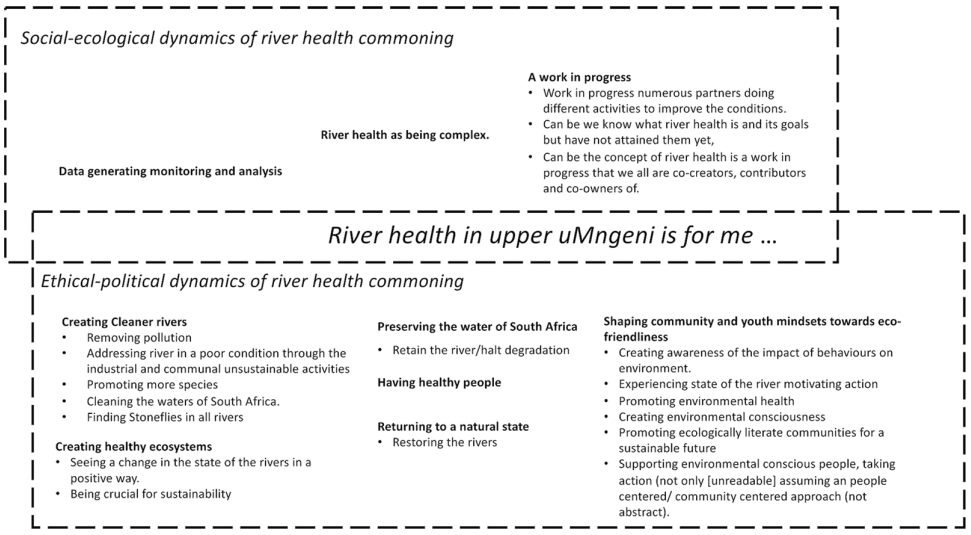

Figure 4: Social-ecological and ethical-political dynamics of river commoning activity (bringing river health into being).

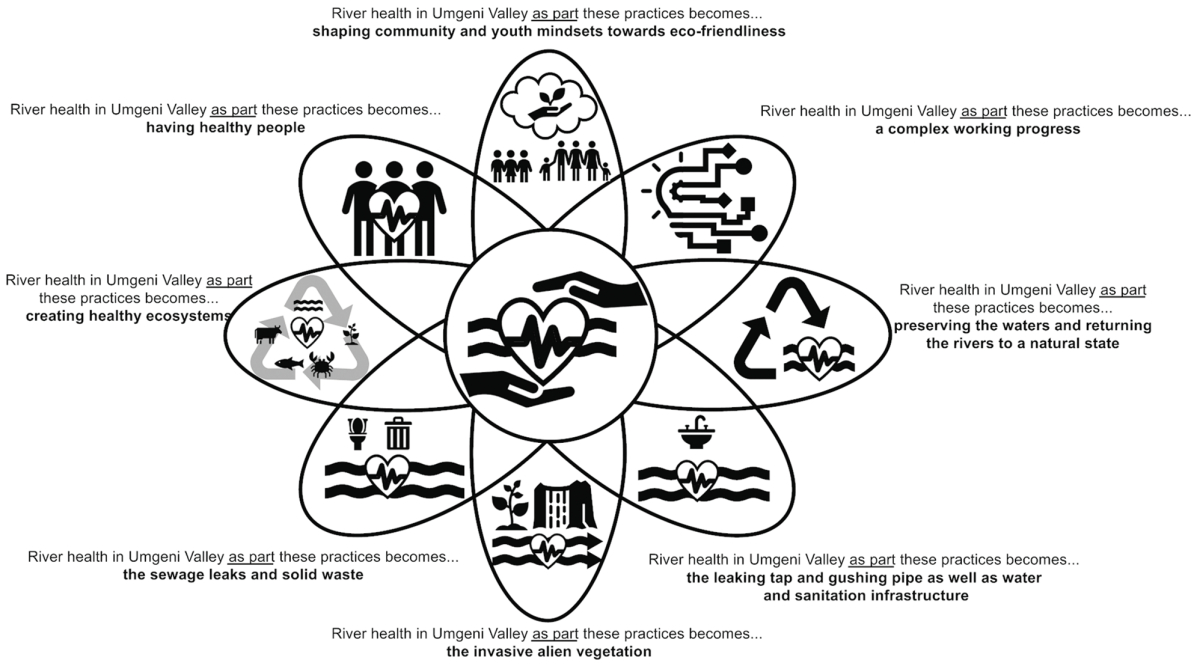

Figure 5: The expansive commoning activity of river health in the upper uMngeni.

Our study shows that the river health commoning activity, from the AEN project, emerged as an open-ended co-creation process between River Rovers and Enviro-Champs, Data Detectives and River Commons partners, around the 'health' of the river. This extends the notion of river health beyond technical specifications, to the notion of river health as an emerging commoning activity, requiring co-learning, citizen science practices and community engagement. Through this, the sharing of responsibility for river health can be realised by all in the catchment as they come to understand meaning(s) of river commoning activity. It offers extended support for managers who, in most technical river health reports, are given responsibility for river health through expert stewardship.

In conclusion, the paper highlights possibilities of imagining futures where healthy river ecosystems are interwoven with people's health and participation. The AEN project shows that our human health is linked to our rivers, and river health in the practice of citizen science becomes a point of intersection for the health of humans, animals and the environment between the riverbanks and beyond.

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Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. Ethical approval was granted by the Rhodes University Education Faculty Ethics Committee for a low risk study under the research programme 'Citizen-Based Water Quality Monitoring National Review' which was conducted in a partnership between Rhodes University's Environmental Learning Research Centre, the Duzi Umngeni Trust and GroundTruth: approval number: 2019-0536-2030. All ethical procedures were adhered to. The researchers explained the research to participants and ensured that participants understood the purpose of the research and that the information they provided would be treated confidentially and used solely for the purposes of the research. Moreover, where the materials collected are used for publications such as this, it was communicated that no personal names or details of the participants' identities would be revealed.

Data availability

The data supporting the results of this study are available upon request to the corresponding author.

Authors' contributions

M.M., R.T., P.M.: Conceptualisation, methodology, data collection, data analysis, writing – the initial draft, writing – revisions. F.B.: Conceptualisation, project leadership, project management, funding acquisition. C.R.: Conceptualisation, methodology, data collection, writing – revisions. H.L.-S.: Conceptualisation, methodology, data analysis, writing – the initial draft, writing – revisions, project leadership, project management, funding acquisition. All authors read and approved the final manuscript.

Author information

The lead author and visiting postdoctoral fellow M.M., PhD scholars R.T. and P.M., and principal investigator H.L.-S. form part of the Rhodes University Environmental Learning research team, while partners F.B. and C.R. are from participating organisations.

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Citizen science tools for engaged research: Water quality monitoring in remote communities

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Remote areas that lack conventional water-provisioning infrastructure often rely on rainwater harvesting, rivers, pans, reservoirs and borehole-extracted water to meet domestic water requirements. These water sources often have poor microbial quality and chemical composition, the quality of which is not routinely monitored. This study explored citizen science as a tool for Engaged Research and Responsible Research and Innovation, detailing the co-creation of a sustained community-based water quality monitoring program in collaboration with communities in villages in Amakhala Game Reserve (Eastern Cape, South Africa). Without access to other water sources, participants predominantly used rainwater for drinking and cooking (80%), while borehole water was mainly used for cleaning and gardening due to its salty or bitter taste. A hydrogen sulfide (H_2S) water testing kit was used by the citizen scientists to monitor the water quality. The H_2S kits were effective in estimating bacterial contamination, showing a proportional relationship with Colilert® test results conducted in a laboratory. The alignment observed between community-based monitoring results and those derived from scientist-led testing underscores the value of data produced through citizen science initiatives. Sustained participant engagement throughout this research reflected a sense of community empowerment through access to tools that inform their decision-making around water use and treatment as well as investment in the research, indicative of the perceived relevance of the research to community interests. This integration of transdisciplinary data sources holds promise for informing evidence-based decision-making processes, facilitating more effective and contextually informed water management strategies that value and integrate community perspectives alongside scientific insights.

Significance:

Drawing on the principles of Engaged Research and Responsible Research and Innovation, we applied citizen science tools to engage researchers and communities in the co-development of a water quality monitoring program. In addressing a specific area of concern, raised by the remotely situated community around the need for knowing their water quality, the project successfully trained communities in applying water testing tools and fostered agency in decision-making around water treatment. Combined with continuous feedback and communication loops, a high rate of continuity was sustained among the participants.

Introduction

Access to safe drinking water remains a global challenge, exposing communities to waterborne diseases and their attendant consequences on health. Reliance on alternative water sources such as rivers, streams, pans, dams and reservoirs as well as rainwater harvesting and borehole water in rural regions is a common practice already employed in different African countries, including South Africa.[1,2] South Africa specifically has poor water management systems while also experiencing low rainfall. These water sources often have poor quality when considering either microbial presence and/or adverse chemical compositions.[3] Many rural communities in South Africa are therefore reliant on unsafe, untreated, water sources for drinking purposes, risking exposure to waterborne diseases and other adverse health effects.[4] Community knowledge and understanding of water quality and treatment is crucial in the prevention of waterborne disease outbreaks. Lack of access to water quality information and to information on alternative methods of treating water for the community has created a situation of epistemic injustice.[5] The ability of the community to act upon the water quality problem is dependent on understanding specific aspects of water quality and their attendant health implications. Citizen science approaches may offer an opportunity for community-based water quality monitoring to address shortcomings in the routine monitoring of water quality.

Citizen science, as a tool, engages non-scientists in scientific research and processes, encouraging communities to contribute to – or address issues using – science-based approaches.[6,7] Different conceptions of citizen science denote these as being either (i) community-led, where communities identify problems that can be addressed through scientific methods and engage with various stakeholders for problem-solving[8,9], or more frequently, (ii) scientist-led, where scientists invite communities to engage in specific research programmes. For the latter, several examples exist in the literature and in publicly accessible databases: many of these are data-gathering citizen scientist activities that continue to provide valuable information and monitoring in scientific areas that include astronomy, alien plant eradication, wildlife and water monitoring, among others. The inherent capability of involving the broader public in 'hands-on' scientific activities positions citizen science as a pivotal instrument, not only for fostering a deeper appreciation and understanding of scientific concepts but also bolstering science education and literacy within diverse communities.[10,11] Kruger and Shannon[12] also note the potential it holds for democratising science by involving citizens as researchers; the extent to which democratisation occurs arguably being determined by the extent of involvement that citizens have in shaping the research.

Substantial scope exists for meaningful engagement of communities in scientific research, with the extent of engagement determined by both the nature of the engagement and its potential outcomes. Communities having a role in shaping research is advocated for in South Africa's Science Engagement Framework, wherein Engaged

Research refers broadly to engagements between researchers, communities and other stakeholders, at any stage of the research process, and their involvement in the research outcomes. This approach is informed by: "the values of contemporary, post-apartheid South Africa, most specifically the imperative of empowering its citizens to engage with processes and issues that affect them"[13]. This strategy echoes the European Union's Responsible Research and Innovation (RRI) framework with some of its core foci centred on engagement with the public, gender equality, ethics and democratisation of science. One of the defining features of RRI is that it advocates for engagement between scientists and communities throughout all stages of the research and innovation process, ideally from the outset.[14] One of the challenges of RRI is putting this into practise in a way that sustains the engagement and the active participation of impacted communities. While citizen science is often viewed as separate from engaged research frameworks, it offers a set of tools to sustain active community engagement and promote an understanding of science.

This paper offers a case study exploring how citizen science approaches can be embedded into engaged research and RRI frameworks as an approach, not only involving communities in shaping research but also facilitating co-creation between scientists and communities. This study aimed to explore citizen science as a tool that draws on the principles of RRI and Engaged Research to engage communities as citizen scientists. Applying a community-based monitoring citizen science approach, communities of Amakhala and researchers sought to co-develop a community-based programme focusing on monitoring rainwater and borehole water quality in these villages.

In the research, it was hypothesised that the use of H_2S testing kits by citizen scientists would provide an accessible tool for communities to monitor microbial quality of water and that this would correlate with water quality results using IDEXX Colilert® tests conducted in a water quality testing laboratory.

Site of the study

The Amakhala Game Reserve is a private game reserve in a remote area between the cities of Gqeberha and Makhanda, in the Eastern Cape Province of South Africa.[15,16] The game reserve includes seven villages that are home to approximately 200 adults and 80 children.[16] Five of these villages were involved in this study: Leeuwenbosch, Kraaibos, Carnarvon Dale, Brentwood and Beacon Hill (Figure 1). These communities rely on rainwater tanks and borehole-supplied water, the quality of which is not formally monitored.

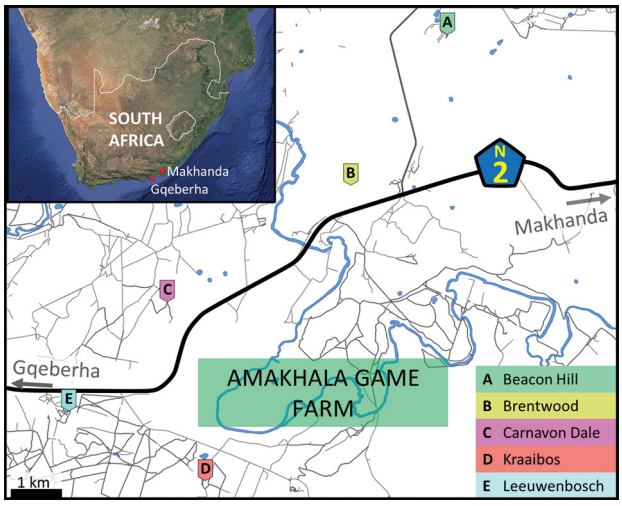
Methods

This study built on a longstanding relationship – an ongoing partnership between the broader Amakhala community and Rhodes University's Community Engagement Division started in 2017, centred on land reform and reconstitution strategies – between community partners and the researcher. This study occurs as part of several other community engagement initiatives and studies that developed from this relationship.

The methodological approach followed four phases, as graphically depicted in Figure 2.

The exploratory phase

This phase commenced with informal discussions held between an existing research team within Rhodes University's Community Engagement Centre, who were engaging communities in the Amakhala Game Reserve on health-related concerns. During the finalisation of that research, informal discussions were held with community members. Small group discussions were held at three sites in Amakhala (Kraaibos, Reed Valley and Leeuwenbosch) in 2019. During these sessions, researchers asked about other challenges that community members experienced due to their remoteness. Community members highlighted concerns about the quality of their drinking water and expressed an interest in knowing the quality of their water. This was consistent with other concerns raised by villagers in the 2017 Community Report, which highlighted the need for improved water supply, access to electricity and better housing conditions.



Source: Maps were generated using: https://snazzymaps.com/build-a-map (all styles are licensed under a Creative Commons licence)

Figure 1: Map detailing the location of the Amakhala villages in which community participants in this study resided, showing their location relative to local roads (grey), the N2 national route (black) and local water sources (blue). Map quadrant from −33.4617; 26.0548 (top-left) to −33.5534; 26.1976 (bottom-right). Top-right inset: map of South Africa, indicating the two major cities closest to the Amakhala Game Farm; Amakhala is approximately mid-way between these two points.

Defining the scope of the research

Subsequently, a survey was conducted with communities in the five villages comprising the study site (Figure 1), to explore the communities' concerns about water quality and to establish their interest in monitoring the quality of their water. At the time of the survey, the five identified villages consisted of 47 households. All the households in these villages were invited to participate; 29 of the households, each represented by one person, agreed to participate and were interviewed as part of the study. The main cited reason for non-participation was non-availability due to work or not being available for the whole duration of the study. Survey questionnaires (Supplementary material) were conducted in person – either individually or in small groups of up to three participants – across the five villages. Questionnaires were provided in both English and isiXhosa and were administered using the Kobo Toolbox.[17]

The Kobo Toolbox[17] is software used to collect, analyse and manage data for surveys, monitoring, evaluation and research. Researchers worked with individual community members on completing the questionnaire, inputting the responses provided into the Kobo Toolbox application. As the participants responded to each question, the researcher typed out the answer and read it back to the participant to confirm correct capture of the response.

Developing the citizen science programme

Based on the insights gathered from both the survey and through informal conversations between researchers and communities, a citizen science community-based water quality monitoring programme was developed. This design aimed to engage the Amakhala community members as citizen scientists, empowering them to actively monitor the quality of their water. The programme entailed four stages: (1) identifying the water quality indicators to be tested and identifying existing tools for said indicators; (2) identifying participants interested in becoming citizen scientists and providing training in the use of testing tools and interpretation of results; (3) citizen scientists monitoring water quality using the H_2S kits over an 18-week period during which (a) communities assessed their water's quality through weekly sampling and (b) periodic paired sampling was performed by researchers to conduct comparative laboratory testing of water quality using Colilert® testing in a laboratory;

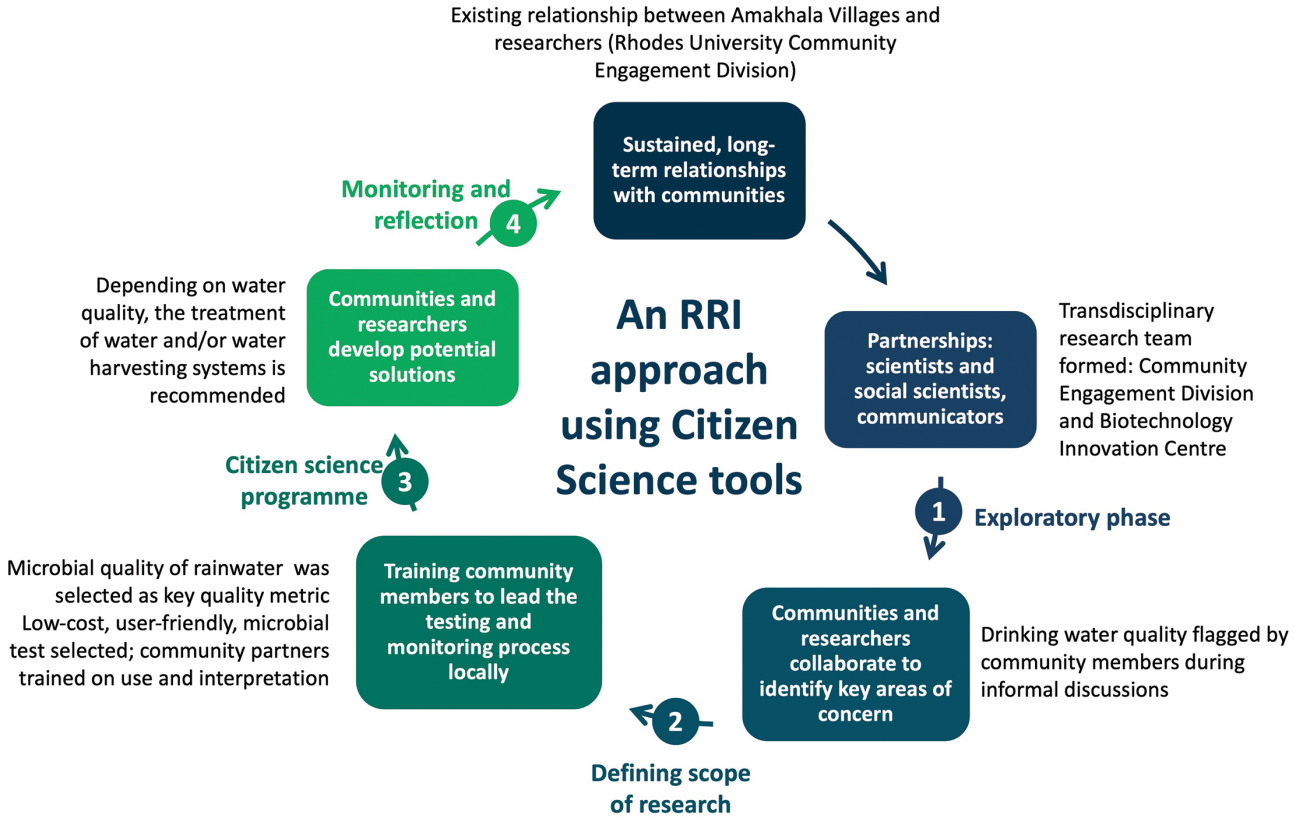


Figure 2: Citizen science tools integrated into the current RRI/Engaged Research Study, centred around developing community-level water quality monitoring tools.

and 4) weekly reflection on results obtained and discussions between scientists and communities.

Language

In the engagements with the community, isiXhosa (an indigenous language of the Eastern Cape Province of South Africa) was used. Code switching between isiXhosa and English for some scientific terms was important to ensure that some concepts and methods were understood by the citizen science participants. The citizen scientists were requested to use the language that they were comfortable using during workshop discussions and when completing the questionnaires. Mji and Makgato[18] support the use of code switching by arguing that language transcends both direct and indirect influences in science education.

a. **H_2S test kit training**

The hydrogen sulfide (H_2S) test kit for the detection of coliform bacteria in water is a microbial testing approach used in several studies[19-22], using purpose-built low-cost H_2S testing kits. Test kits were constructed following reported protocols.[19]

A demonstration of the use of the H_2S testing kit was carried out with community members, in groups of up to three people. Each person was provided with five test kits and was trained on the use of the kit under the guidance of the researcher. A brochure detailing the H_2S test kit methods and the interpretation of results was developed and provided to each citizen scientist, in both English and isiXhosa (Supplementary material). Each brochure included a description of possible water treatments that communities could follow when the tests indicated the presence of microbial contaminants.

b. **H_2S test kit validation**

To ensure the scientific validity and authenticity of a citizen science project, it is essential to adhere to the universal principles of science studies, as articulated by Silvertown.[23] These principles emphasise the validation of the data collected and the standardisation of data collection methods. Furthermore, it's crucial to provide citizen scientists with feedback on their contributions, serving to acknowledge and affirm their role in the project.

To validate the H_2S test kit as a tool for use by the community in Amakhala to effectively monitor water for bacterial contamination, samples of rainwater were also collected by the researcher and further analysed on the same day for the presence of total coliforms using standard Colilert® assays[24]; this is discussed in greater detail below.

Monitoring the citizen science project and reflection

Evaluating the success of citizen science projects requires a comprehensive approach due to the diverse objectives and outcomes they encompass.[25,26] Key metrics include tracking both the volume and diversity of participation; ensuring the accuracy, precision and usability of the collected data; determining whether an increase in participants' knowledge and skills occurs.

The citizen scientists of the Amakhala communities monitored the microbial water quality of their water sources for 18 weeks. At the beginning of each week, each citizen scientist received five H_2S water testing kits. They used all five kits by testing a single water sample once a week, measuring coliform contamination. Following 72 hours' incubation, participants recorded the number of issued H_2S water testing kits (out of a total of 5) that were positive. Placing the sealed test bottles in a dark area at room temperature, typically between 25 °C and 37 °C allowed for incubation of the samples. Temperatures lower than this interval could affect the incubation of the H_2S-producing bacteria.

Paired water sampling was conducted periodically (Weeks 1, 7 and 18), using Colilert® testing conducted by the researchers. The samples for Colilert® testing were collected using 1-L Schott bottles and stored on ice for transportation; samples were processed within 12 hours of sampling.[22] These samples were collected at the same time and place as the H_2S sampling sites.

Throughout the 18-week monitoring phase, weekly informal meetings and discussions were held between researchers and the community members serving as citizen scientists to facilitate the interpretation of results and stimulate conversations on appropriate water treatment techniques. These interactions served as a platform for ongoing engagement, knowledge exchange and collaborative problem-solving between the researchers and community members. The discussions also helped identify the scope for future research, especially with respect to the limitations of the test kit and treatment options.

Data analysis

Quantitative information extracted from the questionnaires' answers, from the H_2S kits validation and the responses of the citizen scientists' water monitoring using the H_2S kits were evaluated statistically, using *R* (*v* 4.3.1), using the *ggplot2* package to generate graphical summaries of this information. Specific inferential statistical tests used to evaluate significant differences between samples can be found within the captions for these summaries.

Results

Exploratory survey

During the exploratory phase, the researchers further probed which specific aspects were of greatest concern: knowing their water's quality or developing tools to treat water. Community members highlighted that a preference for first knowing the quality of their drinking water was of specific importance, stating that having access to the information would allow them to make determinations as to its safety for consumption. These informal discussions shaped the nature of the research direction and provided the scope for the survey questionnaire (Supplementary material) and future follow-up site visits.

Findings from surveys and site-visit observations

A total of 29 community members agreed to participate in the survey, each as representatives of their households (ranging between 1 and 10 members) (Figure 3). The sections below summarise the demographic profile of the study's participants (Figure 3) and some of the pertinent responses captured by the survey.

Household sizes varied considerably within the cohort, from members living alone to those living in 10-member households. Larger households were noted among the participants from Brentwood (with a median household size of seven), compared to those of Carnarvon Dale (all respondents indicating that they lived alone) or Leeuwenbosch (median household size of two) (Figure 3A). Larger household sizes were of specific relevance as an indication of an increased reliance on the available water sources. Comparing participants' age and gender (Figure 3B) indicated that significantly more female than male participants formed the cohort within this study: 72% of participants were female. The participants were predominantly aged between 30 and 55 years, with a median age of 39. No significant difference between the distribution of ages between genders was noted in this study.

Water demand and supply

All participants indicated that they accessed both stored rainwater and borehole-extracted water to meet their daily water requirements. Given the location of the surveyed area, being situated in a nature reserve, the communities did not indicate river water as an accessible source of water for them.

The borehole water sources at the Amakhala villages were provisioned by the managers of the Amakhala Game Reserve. These were accessible in all the villages at Amakhala: some villages have outlets/taps installed in household yards; in others, borehole water is temporarily stored in a communal water tank.

The majority of community members among the villages of Amakhala collect rainwater from their rooftops. However, due to the high cost of conventional rainwater tanks, 68% of the households in Amakhala use conventional water storage tanks, while others use alternative containers for collecting water (Figure 4).

There were some significant differences between the purposes of borehole and harvested rainwater used by the participants (Figure 5).

As illustrated in Figure 5, participants highlighted that the activities they were most likely to use rainwater for in their households are for drinking (with significantly more participants indicating that they used rainwater than boreholes to meet this need) and to meet cooking requirements. Of the 55 responses captured for the uses of rainwater, 44 were for these two specific uses, that is, 80% of the total use of rainwater.

Conversely, borehole water was used by the participants predominantly for cleaning purposes (laundry and dishwashing), as well as for

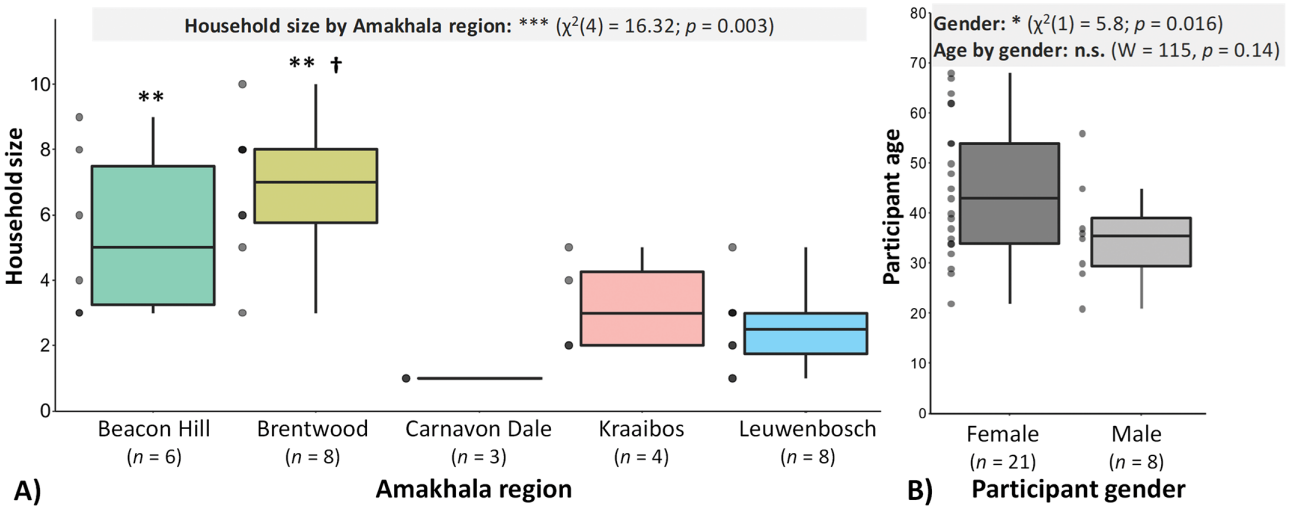


Figure 3: Summary of demographic statistics of the composition of the citizen scientist participants. **(A)** Distribution of the household sizes of the participants, compared to the regions of Amakhala in which they reside. The distribution of the participant numbers was not found to differ significantly by their residential region (Fisher's exact test; $p = 0.784$). **Annotations:** Inset text shows results from Kruskal–Wallis testing for significant differences between the medians of samples. ** - significant difference in sample median, compared to Carnarvon Dale sample; † - significant difference in sample median, compared to Leeuwenbosch sample. Significantly different samples identified using Dunn's test, modified using the Benjamini–Hochberg procedure ($p \leq 0.02$). **(B)** Comparison of the ages and genders provided by participants. **Annotations:** Inset text show comparison of the proportion of the respondents' gender distribution and the comparison of the distributions of age by gender.

gardening/irrigation. The majority of respondents (86%) identified that the borehole water was salty or bitter, making it unsuitable for cooking and drinking. No filtration systems were noted on the borehole water accessed by surveyed participants.

Figure 4: Various methods of rainwater harvesting employed by participants in the Amakhala region.

Most (66%) of participants indicated that the quantity of water that they receive is insufficient for their household's requirements. Participants highlighted a lack of sufficient rainwater, due to the variability of rainfall in the region as reported elsewhere.[27]

Water source treatments by citizen scientists

Of the 28 participants responding to questions regarding water treatment, 15 (54% of respondents) reported that they do not treat the water prior to drinking it. Given the large proportion of respondents who identified rainwater as being their source of drinking water, many of the answers given related to treatment of rainwater.

Participants who treated their water often used a variety of methods. Drinking water was treated by the cohort by straining/filtering the water ($n = 6$); boiling ($n = 3$), chlorination ($n = 2$); allowing sediment to settle ($n = 2$); placing water in a fridge for a period of time ($n = 2$). One participant added small amounts of paraffin to tanks and waited 3 days before drinking.

Boiling and chlorination are widely recognised as effective means of treating water for safe consumption.[28] However, despite their efficacy, most participants do not treat their water using these methods.[29] This discrepancy can be attributed to various factors, including increased trust in alternative sources like rainwater[30] and the cost implications of treating water in these ways[9,31]. Additionally, contamination of the water by participants was identified by the presence of visible organisms and debris: worms ($n = 5$), insects (n = 2), sand and mud ($n = 2$), and leaves ($n = 1$). None of the participants' rainwater harvesting systems had filtration devices installed (Figure 4); this may explain why these contaminants were evident in rainwater supplies and why filtration and/or sedimentation of the rainwater were the most-common treatment options among the cohort.

Given the prevalent use of rainwater as a main drinking source, and the noted microbial health risks associated with its usage, estimation of microbial contamination was selected as the main quality parameter to be evaluated. A low-cost means of measuring this already reported on by the researchers[19] was selected.

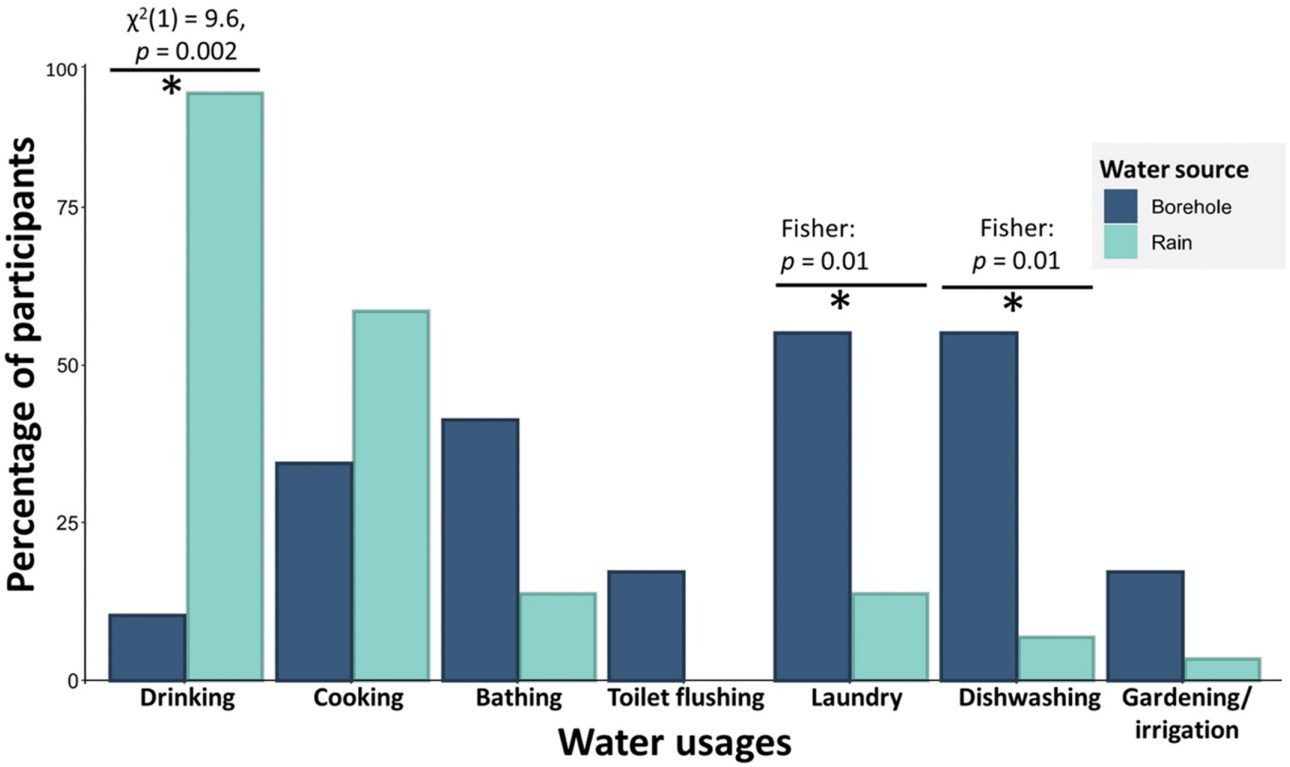


Figure 5: Responses to questionnaire sections discussing differences in the usage of water by the participants, based on the source of the water (borehole and harvested rainwater). **Annotations:** Individual tests on the frequency at which a specific water source showed a significantly higher extent of usage are annotated. Depending on the composition of the samples, either Fisher's exact test (for samples with $n < 5$) or chi-squared tests are annotated.

Evaluation of the H_2S testing results by citizen scientists

When asked whether they were interested in testing their water supplies, all participants expressed that they would like to. As a result, all participants received training during the individual village workshops.

Each citizen scientist recorded their test results in a supplied booklet. Results were transcribed and translated using the traffic light system (Table 1) developed to communicate the results obtained from H_2S kits in a user-friendly manner.[19]

The traffic light system (Table 1) interprets the number of test kits into a colour-coded recommendation list: Green (0 positive kit results) indicates water with a low microbial load that is safe to drink: Orange (1–4 positives) indicates water that might contain faecal contamination and needs treatment before drinking, that is, boiling; Red (5 positives) indicates water that is unsafe to drink without extensive treatment.[19] Boiling was recommended as a treatment strategy, as it was effective, low-cost and geographically accessible. If a Red result was obtained, researchers discussed additional water treatment strategies.

The findings of paired water samples jointly analysed by the citizen scientists (using the H_2S kits) and by researchers (using the Colilert® detection method under laboratory conditions) are compared in Figure 6. A total of 84 samples, from both rain and borehole water, were obtained and analysed in parallel. The Colilert® system has two separate tests that estimate total coliform bacteria (including *Escherichia coli*) and *E. coli* levels in water samples, while the H_2S test is a broad coliform indicator (including *E. coli*).[30,32] Therefore, the responses of the total coliform counts obtained by the Colilert® system are compared to H_2S responses.

Table 1: Interpretation of H_2S kit test responses using the traffic light system[19]

Number of positive H_2S kits	Colour representation	Interpretation of water quality
0	Green	Safe to drink.
1 to 4	Orange	Water requires further treatment (boiling) before consumption.
5	Red	Do not drink! Report to the councillor.

In general, paired testing of the water samples indicated that the H_2S kits provided an accurate estimation of the bacterial contamination of the water samples (Figure 6). A proportional relationship between the number of positive H_2S kit responses per test and the total coliform estimates obtained by the laboratory-based Colilert® system is evident. In particular, water samples producing three or more positive H_2S responses had significantly higher bacterial estimates than those producing two or fewer H_2S responses (* annotation, Figure 6).

As Colilert® responses measure the most-probable number (MPN) of metabolically active cells, direct comparison between the results obtained by this method and those required by national water-quality guidelines (which measure bacterial presence as colony-forming units (CFUs)) is difficult; generally, MPN provides a higher estimate of cell numbers compared to CFU.[33] Therefore, similar to other studies[30,34], we distinguish between water samples that are of intermediate-risk (<10 MPN/100 mL) and those that are high-risk (≥10 MPN/100 mL) when comparing the risk estimated by the H_2S kits and that determined by the laboratory-based Colilert® measurement in Figure 6.

False-positive and false-negative responses were based on the above risk-based definition. A total of 8 samples of the 84 produced no positive H_2S kit responses, while 76 produced at least one positive H_2S kit result. False-positive samples generated at least one positive H_2S kit result per test but also produced Colilert® measurements of <10 MPN/100 mL; conversely, false-negative samples produced Colilert® measurements of ≥10 MPN/100 mL, but the H_2S kits by citizen scientists failed to generate detectable signal. In this study, the false-negative and false-positive rates estimated by this study are 25% and 8%, respectively. This provided a calculated sensitivity, that is, Equation 1:

$$\frac{100 \times true\,positives}{true\,positives + false\,negatives} = \frac{100 \times 66}{66 + 2} \qquad \text{Equation 1}$$

and specificity, that is, Equation 2:

$$\frac{100 \times true\,negatives}{true\,negatives + false\,positives} = \frac{100 \times 6}{6 + 10} \qquad \text{Equation 2}$$

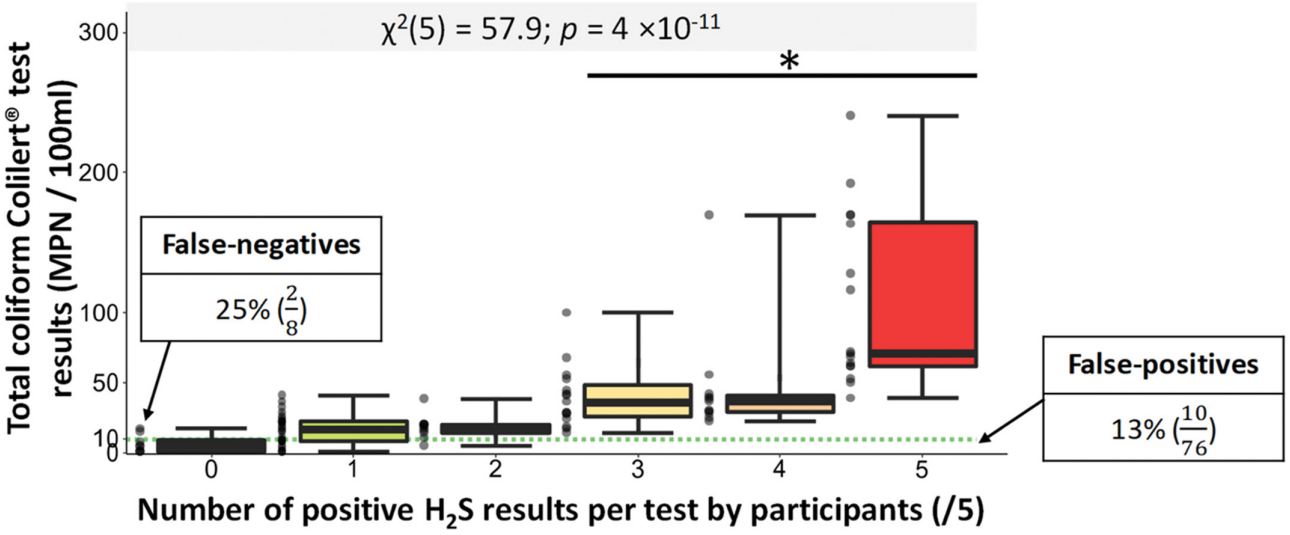


Figure 6: Comparison between the Colilert® test results obtained in the researchers' laboratory and the number of positive H_2S responses generated by citizen scientists for a given water sample. Both rainwater and borehole water source samples are included here. Green dashed line shows the boundary between samples that measure intermediate-risk Colilert® measurements (< 10 MPN/100 mL) and higher-risk samples. **Annotations:** Inset text shows results from Kruskal–Wallis testing for significant differences between the medians of samples. * - samples showing significantly higher Colilert® (R) test response, compared to the samples producing zero positive H_2S responses. Significantly different samples identified using Dunn's test, modified using the Benjamini–Hochberg procedure ($p \leq 0.05$).

for the citizen science testing of 97% and 37.5%, respectively, comparing very favourably to previous studies in which researchers compared both the H_2S kit results and Colilert® systems under laboratory conditions.[22] This study shows an increased sensitivity compared to the previous study (from 71% to 97%), while the decrease in specificity (from 100% to 37.5%) may be assigned to the small sample size of the water samples that did not elicit an H_2S response (only eight samples, of which six were true negatives and two false negative samples having Colilert® measurements close to the 10 MPN/100 mL threshold value), coupled to variability in sampling and incubation conditions between the citizen scientists and the researchers in the previous study. The use of a single test kit for sampling was reported to have 64% reliability by Nhokodi and his colleagues[19,22]; increasing the sample size to five kits per sample improved reliability to 99.4%[19, 22].

Overall, this finding underscores the potential of H_2S water testing kits in detecting water quality issues, with Colilert® measurements serving as a robust validation mechanism. The overall testing method is very sensitive to the presence of bacterial contamination in the existing water sources, but test specificity will require further addressing: while those samples that produced no detectable H_2S responses maintained low coliform estimates (Figure 6) compared to other samples, two of these eight measurements failed to identify a moderate risk of microbial contamination in their water samples. The findings contribute to community health awareness, emphasising the need for vigilance in addressing false negatives to ensure water safety and supporting a comprehensive approach to water quality monitoring.

Of the 29 participants, all 29 elected to evaluate their rainwater sources weekly, while 15 of them additionally measured borehole water quality weekly. Of the possible total of 792 tests, 767 test results were returned by the citizen scientists at the end of testing, corresponding to a 96.8% completion rate by the cohort. Figure 7 presented the distribution of H_2S test kit responses over the 18-week period (Figure 7).

As measured by the H_2S kits, water quality varied considerably from household to household and from week to week (Figure 7). This variation prevented any analysis of the water quality as factors of time or of residential area among the participants (data not shown). While the survey indicated that rainwater was extensively used and trusted by the citizen scientists (Figure 5) and was often consumed without treatment, the findings presented in Figure 7A indicate that extensive variation in the quality of the rainwater existed. While 22 of the 29 participants recorded H_2S kit measurements of zero at some point of the testing period (indicating a lower risk of consuming the water without treatment); only two (participants 11 and 18) had consistently low H_2S measurements (✔ annotations; Figure 7). Comparatively, all participants recorded H_2S kit responses of three and above, indicating significant microbial contamination of the water, at some point during the study (Figure 6); three of the participants (participants 4, 15 and 26) measured consistently high risks of drinking their rainwater untreated (× and × annotations; Figure 7A).

Borehole water (Figure 7B) had more consistent water quality compared to rainwater but showed elevated levels of risk overall. The aggregate distributions of the H_2S test responses (box plots in Figure 7) showed that rainwater generated a median response of two positive H_2S tests per sample, while borehole samples overall had three, representing a significantly higher aggregate response ($W = 47075$; p-value $= 4\times10^{-12}$). Similarly, four of the participants measuring their borehole water reported consistent risks to drinking it untreated (× and × annotations; Figure 7B).

Among both water sources, 'orange' (1–4 positive kits) were reported in 67% of instances during the course of the sampling by the citizen scientists, while 'red' (five positive kits) were 14% of all tests, making a total of 81% of the water samples carrying some risk of microbial contamination when consumed without treatment.

In weeks in which five positive kits were reported, researchers and affected participants discussed strategies for treating the water source, including clearing out the water tank, cleaning gutters or boiling water before consumption. In informal conversations during the weekly sampling and reporting, community members would express that they were amenable to treating their water using these strategies; however,

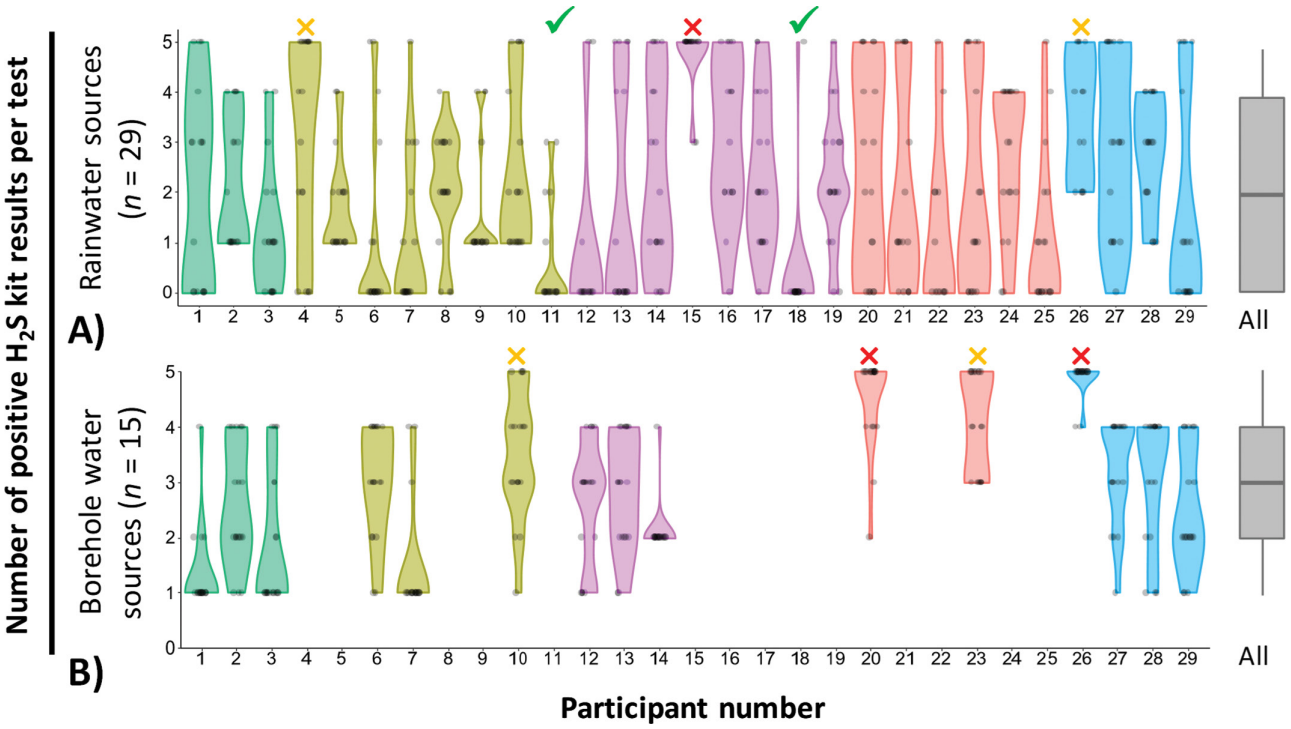


Figure 7: A comparison between the H_2S results of the rainwater and borehole water, as monitored by the citizen scientists at Amakhala. (A) Rainwater sources ($n = 29$). (B) Borehole water samples ($n = 15$). Combined violin and dotplots show the distribution of individual responses, while the box plots at the end show the distribution of the combined H_2S kit results for the two water sources. Violin plot colours indicate the residential area of participants, as depicted in Figure 3. **Annotations:** ✔ generally safe water: over 75% of measurements produced H_2S kit responses of zero; × generally unsafe water: over 75% of measurements produce H_2S kit response of 5; × generally unsafe water: a one-sample Wilcoxon rank test against the hypothesis that the samples are drawn from a population with a median measurement lower than 4, $p < 0.025$.

they were discouraged by the cost implications. Subsequently, some of the citizen scientists discussed boiling the water using outdoor fires and storing it for use over a longer period, decreasing electricity costs. Additional solutions included seeking financial assistance or subsidies from various stakeholders and exploring community-led initiatives to pool resources for water treatment. By acknowledging and discussing these cost implications, researchers and community members discussed potential solutions, including finding low-cost alternative treatment methods. These discussions and problem-solving sessions provided a platform for the community of Amakhala to strategise and find feasible ways to overcome cost barriers, supporting them to solve problems through changes in practices.

Discussion

Through active participation, interpretation of the H_2S kit results, and discussion of test-informed water treatment strategies, the citizen scientists communicated their ability to make informed decisions and take action to ensure water safety. Being a community focused activity, participants shared and discussed findings among themselves, frequently consulting one another when they were unsure of processes. The high completion rate further signifies continued agency and interest in engaging in the monitoring process.[35-39]

During training workshops, communication channels were established, and the researchers could provide instructions, guidance and answer questions. This initial interaction set the foundation for ongoing communication throughout the project.[40,41] Weekly data collection and feedback sessions at each of the villages maintained these channels, providing an avenue for participants to report results and discuss challenges during the water quality monitoring. These sessions enabled citizen scientists to analyse the water quality results together with the researchers and have further conversations around monitoring practices and mitigation strategies.[40,41] This feedback loop may have contributed to the completion rate of 96.8% by the cohort during the 18-week testing period (Figure 7), and through a culture of open communication and helped to ensure the accuracy and reliability of the collected data. This collaborative nature of the programme, applying RRI and engaged research principles in agenda setting in the approach, may have fostered a sense of shared ownership and active involvement in the scientific process.

Conclusions

Insights into the complexity of this form of community-based water quality monitoring have highlighted the need for a rapid water quality test that can enable communities to test their water and receive results within hours. A limitation of this approach, identified by both communities and researchers, is the validity of the test results given the three-day incubation period required to obtain results. Communities are also reliant on access to the water testing kits provided by researchers. Reflecting on this research, and with knowledge of the specific contextual requirements and available resources, a novel testing technology was identified that is currently under development by the researchers, and which aims to provide more rapid results in a sustainable way. Community participants expressed interest in participating further in the evolution of this new technology, validating the use of a citizen approach in RRI and highlighting how the iterative nature of engaged research ensures community engagement from the outset and throughout the project cycle.

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Data availability

The data supporting the results of this study are available upon request to the corresponding author.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. This study was approved by the Rhodes University Human Ethics Committee (RU-HEC), with the approval number 2021-1415-5941.

Authors' contributions

T.N.: Conceptualisation; methodology; data collection; sample analysis; data analysis; validation; writing – the initial draft; writing – revisions; funding acquisition. R.F.: Conceptualisation; data analysis; validation; writing – revisions; student supervision. J.C.B.: Conceptualisation; methodology; data analysis; writing – revisions. J.L.: Conceptualisation; methodology; writing – revisions; student supervision; project leadership; funding acquisition. All authors read and approved the final manuscript.

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Stakeholder contestations of water quality use and management in the Vaal Barrage catchment

The water resources within the lower section of the Upper Vaal catchment, where the Vaal Barrage is situated, are highly utilised and developed, and water quality regulation has become a contested space between resource users and the regulators. The credibility and scientific defensibility of discharge standards in water-use licences (WULs), the relationship between upstream and downstream waste loads, the relationship between flows and water quality standards in WUL, and the water quality components of the resource quality objectives (RQOs) are being contested. This study explores the perceptions and motivations underlying these contestations as a contribution to scientific understanding of water quality management in a highly developed system. Perceived unrealistic RQOs, perceived lack of scientific credibility of the methods for deriving water quality standards in WUL, data inadequacy, as well as poor institutional capacity were identified as the top motivations for contesting applicable regulatory instruments in the catchment. Punitive measures, incentives, and education and awareness-raising were identified as key to accelerating compliance. Overall, this paper contributes to our general understanding of the intricacies of water quality management within a contested space.

Significance:

Water quality management in South Africa is increasingly becoming a contested space, particularly in catchments that are highly developed and utilised. The findings in this study imply that (1) there is a need for a multi-pronged approach to increase water quality compliance, (2) there is a need for trust within the regulatory system to foster confidence among actors and stakeholders, and (3) transparent, open processes and scientifically credible and defensible methods, and data are needed for deriving standards in water-use licences (WULs).

Introduction

The lower section of the Upper Vaal catchment is among the most utilised catchments in South Africa because of its location in an economic heartland of the country.[1] Factors such as an expanding industrial footprint, a growing human population, and increasing agriculture, mining and informal settlements impact the Upper Vaal River and the Barrage.[1] These activities have led to reports of high levels of chemical and microbial pollutants in the lower section of the Upper Vaal River system.[2] Pollution poses a threat to both human health and further economic growth, as well as threatening ecological integrity, and the sustainability of the ecosystems upon which humans rely.[3,4]

Water quality remains a challenge in the Upper Vaal River catchment.[5,6] For example, salinity has remained an important water quality issue in the Vaal River and has received the most management attention.[7] Elevated nutrient levels, metals and high bacterial counts have also been reported in the Upper Vaal, indicating water quality related risks to both human and ecological health.[8,9] Water quality is impacted by diverse sources in the lower section of the Upper Vaal River, but the key contributors to deteriorating water quality include failing municipal treatment works (WWTWs), mine water discharges, irrigation return flows, urban run-off, industrial discharges, and atmospheric depositions.[7,10] As noted by McCarthy et al.[11], the collapse of the Klip River wetlands has further compounded the water quality situation downstream as these wetlands are no longer able to effectively remove nutrients. Water quality thus remains a complex challenge in the lower section of the Upper Vaal River system.

In South Africa, water pollution is controlled through environmental policies and regulatory instruments such as the South African national water quality policy and strategy[12], as well as water quality licensing, which is an important water quality regulatory instrument[13]. Examples of other instruments that are used to manage water quality and pollution in South Africa include general authorisation, water quality guidelines, the waste discharge charge system, the Green Drop programme, and environmental impact assessments.[14] These instruments are collectively referred to as source-directed control (SDC) measures. Equally important are the resource quality objectives (RQOs), reserve determination, the national classification system, and water resources classification of significant water resources, all of which are deployed towards protecting water resources. They are collectively referred to as resource-directed measures (RDMs).[15]

Odume et al.[14,16] have shown that water users in the catchment of the lower section of the Upper Vaal contested applicable water quality regulatory instruments such as discharge standards in water-use licences (WULs). A study carried out by Odume et al.[16] noted that water resource users and the regulators were contesting the scientific defensibility of the standards in WULs; the relationship between RQOs and standards in WUL; the implications of upstream waste loads on the standards in the WUL of downstream users; the relationship between flows and water quality; and the relationship between diffuse and point source pollution. These contestations led to tension between water resource users and the regulators in the catchment and have presented themselves as critical barriers to achieving sustainable water resource utilisation.

Contestation may be driven by water resource users' diverse values, perceptions, and motivations for water use. Jones et al.[17] define values as more strongly held than attitudes underpinning decisions and behaviour. For example, in the lower section of the Upper Vaal system, where the Vaal Barrage is situated, stakeholders have various reasons for water resource use, such as industrial use, mining, and agriculture, all of which are driven by economic benefits. The motivations for water use may contribute to the contestations of the applicable regulatory instruments, particularly if water resource users perceive that such instruments may impact the sustainability of their businesses and overall interests.[18] Understanding the social dimension of environmental problems is fundamental to understanding how stakeholders perceive and interpret regulatory instruments.[19] Overall, motivations in this study describe the 'why' stakeholders choose to contest the water quality instruments, particularly the discharge standards in WUL, the way such discharge standards were derived, and the relationship between discharge standards in WUL and the water quality component of the RQOs.

Given the highly industrialised, and diverse users of water resources within the catchment, downstream water users within the catchment have requested the regulatory authority to clarify how waste loads generated by upstream users were considered when deriving standards for downstream users.[14,16] Furthermore, downstream users in the catchment emphasised the need for stringent standards and targets for upstream users to control water quality impact and to meet the RQOs.

What is clear from these contestations about water quality in the lower section of the Upper Vaal system is the necessity to draw on a diversity of approaches, including a command-and-control to one that considers the interests and values of diverse stakeholders within the catchment.[20] Stakeholder engagement can assist in addressing the water quality challenges and gain community support, trust, and buy-in. Despite the identified contestations over water quality use and regulatory instruments in the lower section of the Upper Vaal[14,16], no study has explored the perceptions and motivations underlying these contestations. This study fills this gap as a contribution to the scientific understanding of water quality management in a highly industrialised and complex catchment.

Methods and materials

Study area description

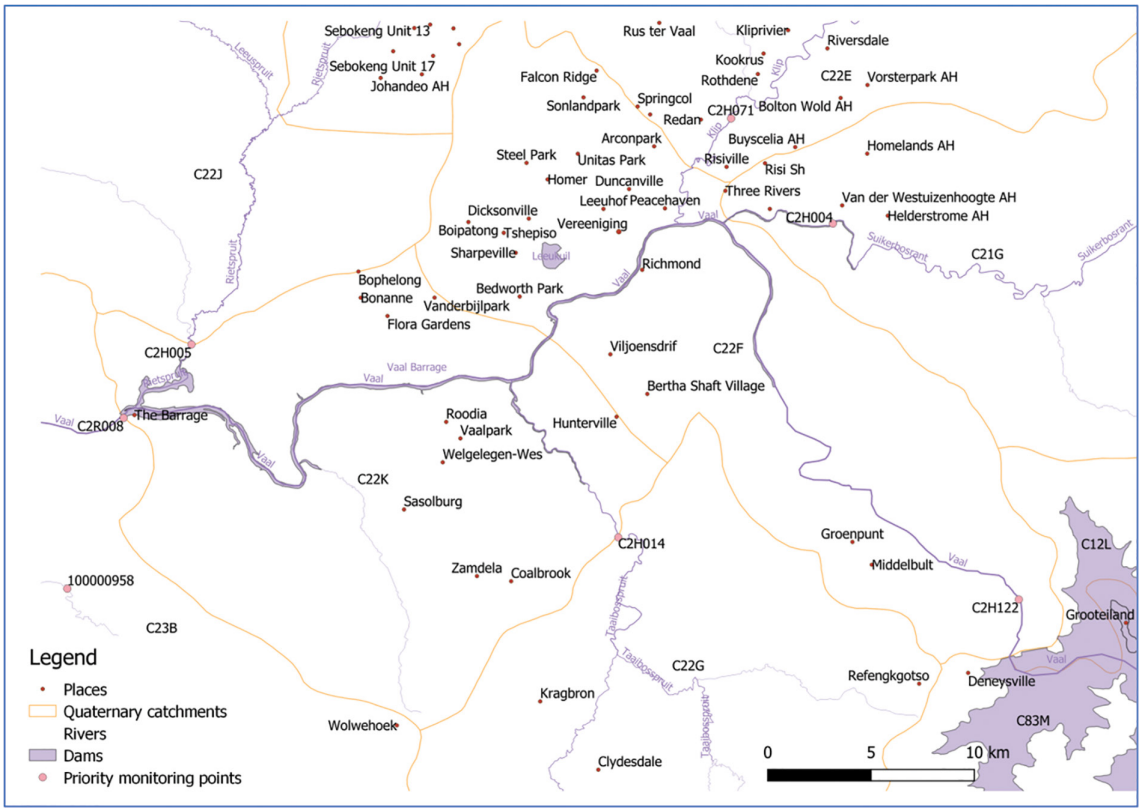
The Vaal River flows from the Drakensberg Mountains in the eastern interior; it then reaches the confluence with the Orange River before discharging into the Atlantic Ocean.[21] The Klip River, Little Vaal, Wilge, and Waterval are the main tributaries of the Vaal River. The Vaal River is regarded as the hardest-working river in South Africa as it is highly utilised within the economic hub of the country. The Vaal Barrage catchment lies within the quaternary C22K catchment, as shown in Figure 1. The Vaal Barrage was completed in 1923, and it was intended to supply potable water to the surrounding areas, but its purpose has since evolved, supporting many wet industries, and its water quality has been severely impacted.[22]

The demography in the Upper Vaal catchment has been extensively influenced by economic activities over the years, especially the downstream catchment, where the Vaal Barrage is situated. The completion of the Vaal Barrage stimulated employment and economic opportunities that led to the beginning of urban development and, ultimately, to an increased population that is now estimated at 10 million people.[1] The Barrage also led to an increase in economic activities such as mining, commerce, manufacturing, and farming.[23]

Water quality in the lower section of the Upper Vaal River and the Barrage is heavily impacted. Unacceptable levels of total dissolved solids (TDS), total suspended solids (TSS), toxic metals, and faecal coliforms have been reported.[24]

Theoretical framework, sampling strategy and data collection

The study draws on social constructivism as a theoretical lens because it argues that knowledge and understanding are constructed jointly by individuals through their experiences.[25] In a sense, social constructivism



Source: Odume et al.[16] (reproduced with permission)

Figure 1: The Vaal Barrage catchment showing quaternary catchments, rivers and dams.

sees human beings as capable of rationalising their experiences, constructing mental models of these experiences, and communicating these through languages.[25] These experiences, the constructed mental models, and the way these are communicated play a role in people's perceptions and views about the world around them. This theoretical framework was considered appropriate for exploring why and how people may perceive water quality in certain ways and, thus, the contestations that may arise from these.

The study utilised a purposive sampling technique, deliberately targeting research participants with interest, experience, and in-depth knowledge of water quality in the study area. Participants were also selected on the basis of a previous study by Odume et al.[14] Nineteen participants were engaged through a semi-structured questionnaire. They represented industries, governments, communities, non-governmental organisations (NGOs), and state-owned enterprises (SOEs). The sample size was considered adequate because the intention was to select participants with expert knowledge of the subject matter and who also had experience of the local water quality issues and the ongoing contestations.

To gain insight into the motivations, perceptions, and values underpinning water quality contestations in the study area among the expert stakeholders, a mixed-methods approach was utilised involving participant observation, semi-structured interviews, and document analysis.[18] Data from all three methods were then triangulated to obtain in-depth insights into the contestations of water quality instruments in the study area. The adoption of the mixed-methods approach ensures validity and credibility of the study.

The semi-structured questionnaire had four sections. The first centred on perceptions of the importance of water resources in the lower section of the upper Vaal catchment, the second on the water quality challenges faced in the system, the third on perceptions of RQOs, and the fourth elicits stakeholders' perceptions and motivations underpinning the contestation of WUL standards, as well as basic demographic information. The questionnaire was administered both electronically and in person during a workshop held on 14 February 2020. Participant observations were undertaken by attending the Leeu-Taaiboschspruit forums on 12 February 2020 and 14 November 2020 in Sasol Kliplapa, Gauteng. Notes were taken with particular attention to water quality management.

Data analysis

The data were analysed using descriptive statistics and thematic analysis.[26,27] The thematic analysis was conducted using the framework developed by Creswell[27]. As the sample size is quantitatively small, the qualitative, thematic analysis provides in-depth insights into the contestations.

Results

Participant demographics

A total of 19 respondents were interviewed for this study. Approximately 74% of the participants work in the public sector, 15% of the participants were in non-profit organisation (NPOs), and 11% in the private sector. Participants' interest in the water sector include water resource management (37%), integrated water quality management (11%), environmental policy implementation (5%), environmental toxicology (11%), environmental protection (16%), and activism/social justice/advocacy/civil society (5%). The participants' level of education and qualifications were Bachelor of Science (15%), Honours degree (5%), Master of Science (57%), and Doctor of Philosophy (21%). The participants' specialisations included ecology, hydrogeology, hydrology, chemistry, and toxicology, as shown in Figures 2 and 3.

Perceptions regarding the RQOs

From the data, three main themes emerged on perceptions regarding the RQOs: (i) unrealistic RQOs and the implications thereof, (ii) poor institutional capacity, and (iii) solutions to RQOs disputes/contestations. When participants were asked whether the gazetted RQOs for water resources for the catchment were realistic, more than a third of them (37%) found the RQOs to be realistic. About 26% of the participants found the RQOs to be unrealistic and 5% regarded them as "very unrealistic". Participants who found the RQOs unrealistic provided reasons such as:

> *I am not convinced that the resource quality objectives have a proper scientific basis. If the objectives are too lenient, we may not see any benefit of setting parameters as per WUL. Some levels are too lenient, but others are too strict.*

> *RQOs are formulated based on the available data, reflecting current conditions of a catchment. Therefore, whether formulated RQOs are realistic or not, depends on whether data used to formulate RQOs were realistic (depending on whether data that was used appropriately reflected current conditions, with sufficient temporal and spatial coverage). In the case of the Upper Vaal Catchment, only data that was available at the time of RQOs formulation was used.*

Approximately 5% of the participants were unaware of the gazetted RQOs. About 26% of the participants were not sure whether the RQOs were realistic or not, as shown in Figure 4. The participants who indicated that the RQOs were realistic gave different reasons; one of the

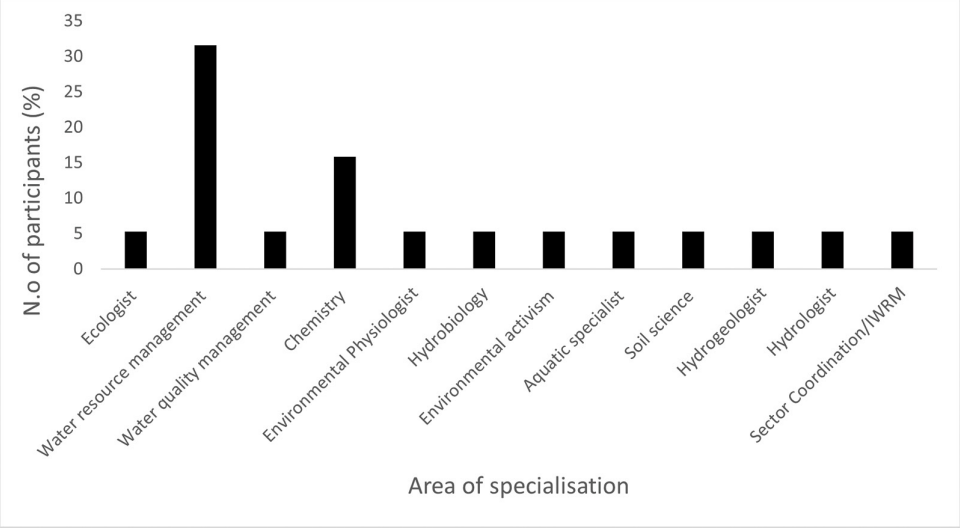


Figure 2: The specialisations of the research participants who were interviewed in this study.

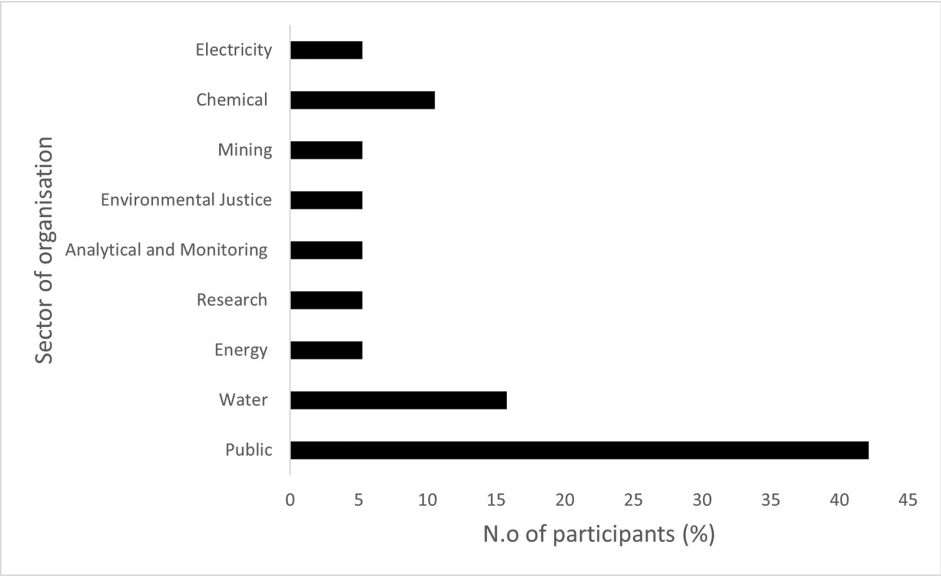


Figure 3: The sectors from which the participants interviewed in this study were drawn.

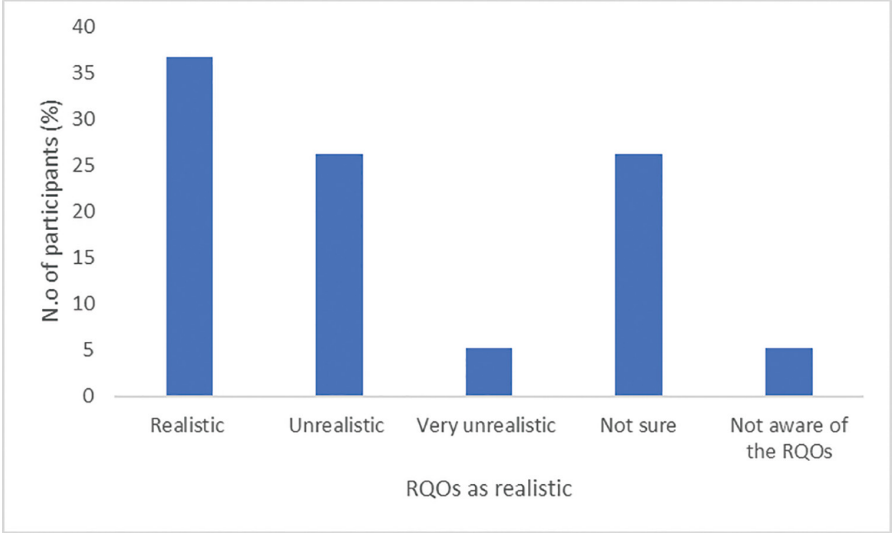


Figure 4: Participants' responses on whether the water quality component of the RQOs was realistic or not.

participants indicated the availability of historical data as the basis as to why the RQOs should be considered realistic:

> *There is enough historical data available to base RQO on, so they should be achievable. The RQOs in most catchments have been determined scientifically so they should be realistic, but mines/ industries have to be more willing to try to comply.*

Participants were asked about the most likely consequences of not meeting the gazetted water quality component of the RQOs. About 63% of the participants agreed that degraded ecosystems and impaired ecosystem functionality would be a serious consequence (Table 1). Twenty-six percent of the participants perceived the risk of human infections and diseases due to impaired water quality as a serious consequence of not meeting the RQOs. About 11% of the participants considered job losses due to increased operational costs related to treating raw water for industrial uses.

Participants were asked to rank the necessary actions required to control water-use activities within the catchment on a scale of 1–5, with 1 being the least important and 5 the most important action(s) required to meet

Table 1: Perceived consequences of not meeting the water quality component of the resource quality objectives (RQOs)

Consequences of not meeting the RQOs	N= % frequency
Degraded ecosystems and impaired ecosystem functionality	63
Job losses due to increased operational costs related to treating raw water	11
Risk of human infections and diseases due to impaired water quality	26
Business profitability due to increased operational costs	0
Impact on water quality-sensitive crops and general agricultural productivity	0
Aesthetic value of the water resources within the catchment	0

the water quality component of the RQOs. About 74% of the participants indicated statutory enforcement and compliance monitoring; 53% felt raising awareness, education, and continuous stakeholder engagement were important; and 58% indicated that the 'polluter pay' principle would be the most important way to control and regulate activities within the catchment. Interestingly, participants ranked voluntary self-regulation, for example, through ISO and incentives/rewards to water users for perceived good behaviour, to be the least important action. Only 11% of the participants ranked self-regulation higher, and only 16% of the respondents ranked incentives for good behaviour high. However, one of the participants reflected deeply on the criticality of drawing on a diversity of approaches:

> *There is not a 'silver bullet'. The available management instruments, i.e. ranging from employing command-and-control approaches (e.g. licencing), to the utilisation of economic instruments (e.g. the Waste Discharge Charge System), to the support of self-regulatory programmes (e.g. ISO 14001), to civil pressure (e.g. management by shame approaches and participatory management through catchment forums) should all be used to achieve improvement and maintenance of resource water quality.*

Institutional capacity to deliver on mandate has been identified as critical in the South African water sector (e.g. Odume et al.[28]). The participants in the present study identified institutional capacity as the primary reason why the RQOs would not be achieved. When the participants were asked whether the RQOs in the catchment were achievable, approximately 68% of them indicated that it was either unlikely or highly unlikely that RQOs were achievable. These participants stressed that institutional capacity was necessary to meet the gazetted RQOs. One of the participants indicated:

> *There is a lack of commitment from the Department* [Department of Water and Sanitation] *in bringing all the role players in to achieve RQOs purposes.*

> *The DWS is finding it more and more difficult to effectively plan, manage and regulate water resources. There are multiple reasons for this. E.g. huge gaps in water quality monitoring. Etc.*

Participants emphasised the role of resource managers and catchment management agencies to meet the RQOs:

> *Once the RQOs are set, they are binding to all who use the resource. RQOs are set for the resource and not for the users* [licence conditions]. *It becomes the responsibility of* [the] *CMA* [Catchment Management Agency] *and regional people* [DWS staff in the regional office] *to implement the monitoring of the set RQO.*

Although most participants were of the view that the RQOs cannot be met, 16% were of the view that the RQOs were likely to be met provided as implementation and assessment plans reflect the current local conditions of the catchment:

> *It is highly likely that the gazetted RQOs would be met, provided that appropriate implementation and assessment plans which reflects current local conditions of the catchment are made available or put in place.*

Interestingly, one participant challenged the notion of the RQO and focused on whether the objectives would result in promoting sustainable resource management within the catchment:

> *Honestly it would vary per catchment; many objectives are not stringent at all, and in fact, if they were met, would result in an unsustainable catchment management situation. An example is the manganese limit set for the Mooirivier, which results in acute toxicity to the receiving environment. While on the other side, there are other objectives that have been set that can never be met, or have no reasonable scientific basis for why they were included, such as the uranium limit in some catchments (with known uranium sources) of 15 ug/L as opposed to drinking water quality requirements as per SANS and WHO of 30 ug/L, not to mention the higher qualities that can be tolerated by the receiving environment, as supported by literature. Therefore, the question is less about the likelihood of achieving these objectives and more about whether these objectives would result in the improvement in the catchment management we really need to see occurring in order to ensure sustainable catchment management for present and future water users (includes the environment). It is highly likely that the gazetted RQOs would be met, provided that appropriate implementation and assessment plans which reflect current local conditions of the catchment are made available or put in place.*

Water quality standards in WULs

Water quality licensing is an important statutory instrument for reducing pollution.[13] Compliance with standards in water quality licences can be enhanced if water resource users view such standards as credible, scientifically defensible, and the process of their derivation as fair and transparent.[16] In the current study, when participants were asked about the key challenges of water quality licensing, participants ranked scientific credibility and defensibility of the methods for deriving water quality standards in WUL as top (Table 2). Other key challenges identified as priorities for WUL were clarity regarding the relationship between RQOs and water quality licensing, as well as institutional capacity, including expert knowledge. Some of the participants, particularly industry representatives, were of the view that the lack of scientific expertise, in particular on the part of the regulators, added to the uncertainty regarding scientific defensibility and credibility of the standards. These participants argued that such uncertainties could lead to the licence conditions being unrealistic. The relationship between RQOs and WUL also featured prominently; the participants were of the view that transparency was

Table 2: Perceived top water quality licensing challenges in the Vaal Barrage catchment and associated rivers. Note that one participant could indicate more than one challenge as a priority

Perceived top water quality licensing challenges	N=% Frequency
Scientific credibility and defensibility of methods for deriving water quality standards in licence conditions	63
Institutional capacity, including expert knowledge, to deal with water quality licensing	58
Clarity regarding the relationship between water quality components of the RQOs and water quality licensing	58
Institutional efficiency and effectiveness in issuing water quality licences	53
Perceived fairness in enforcement, compliance monitoring and sanctions	37
Backlog of licence applications	37
Lack of transparency in the way licence conditions are derived	32
Over-stretched regulators who are unable to cope with new applicants	26

critical as users do not understand the link between the water quality components of the RQOs and discharge standards in WUL. For example, a participant from the public sector opined that:

> *That is why the concept of RDM* [Resource Directed Measures]*, including clarity regarding the relationship between the water quality component of the RQOs and water quality licencing, seems not easy to understand by many of us.*

Participants also referred to institutional capacity in government structures and inadequate financial resources as factors that impede finalising the water quality licensing process. These issues were captured in the participants' responses as follows:

> *The Regulator is highly ineffective due to the lack of funding, multiple layers of poor senior managers, enormous bureaucratic and administrative burden, distrust, centralised decision making, disempowered middle managers and junior staff, rigid work environment that is not conducive to innovation, etc.*

> *Increasing vandalism of water infrastructure and reticulation, the non-payment for water services and the filling of technical positions with unsuitably qualified/ experienced staff are contributing factors, pointing to serious socio-economic challenges; an unsustainable culture of non-payment for services, and the creation of serious essential technical skills shortages. E.g. the performance of WWTWs is getting poorer. WWTWs that previously complied, are finding it more and more difficult to complying, etc.*

The participants were asked whether the process of deriving water quality standards in WUL conditions was consultative enough. Approximately 32% of the participants disagreed, with 11% strongly disagreeing that the process for deriving WUL standards was consultative. About 26% chose to be neutral and 26% of the participants agreed that the process was consultative.

The participants were asked about the actions necessary to stimulate the spirit of self-regulation and compliance with water quality licence conditions. Interestingly, severe punishment for sustained bad behaviour by water users, as well as scientific credibility and defensibility of methods of deriving water quality licence standards, were top for the participants (Figure 5). Most of the participants indicated that these two measures were the most important, each scoring 32%. Participants also viewed institutional efficiency dealing with water quality licensing issues as important (16%). Although incentives as a means of promoting compliance have been promoted in the sector, this did not receive much attention as only 11% of the participants thought that incentives for sustained good behaviour could lead to self-regulation and compliance.

The participants were asked to rank the actions that can be taken to address disputes regarding licence conditions, on a scale of 1 to 5, where 1 represents the lowest priority and 5 the highest priority; 53% ranked negotiation between parties as the highest priority, followed by a reconsideration and reformulation of licence conditions (32%). About 26% of the participants ranked legal challenge in the court of law as the lowest priority, and 11% of the participants ranked an appeal for the licence condition as the lowest priority.

Discussion

The aim of the study was to unpack the motivations and perceptions underpinning the stakeholder contestations of the water quality regulatory instruments such as the water quality components of the RQOs and WUL standards. The water quality components of the RQO are measurable qualitative and quantitative goals that must be met to protect the ecosystems at a desired level of protection.[29] The present study explores reasons why stakeholders within the catchment may contest the RQOs. Most participants in the present study regarded the RQOs as realistic; however, some of the participants were of the view that the RQOs were either unrealistic or very unrealistic. These views may have arisen because (1) the catchment is complex and the RQOs may not reflect this complexity in terms of the multiple point and diffuse sources of pollution[14]; (2) the historical pollution in the catchment could mean that the RQOs do not reflect an appropriate baseline; (3) the RQOs may be relaxed for some water quality variables, yet too stringent for others; (4) credibility and adequacy of the data upon which the RQOs are based, and which in turn informs WUL. Whatever the case may be, the perception that the RQOs are unrealistic implies that stakeholders are less likely to embark on activities that ensure that the RQOs are met, which may be detrimental to long-term economic and social well-being as well as the ecological integrity of the catchment. A study by Sindane and Modley[30] found that households in parts of the study area perceived poor water quality as having detrimental socio-economic effects on members of their households, indicating the need for urgent collective action to improve water quality within the system.

The water quality components of the RQOs are usually formulated through a consultative process in which stakeholders are encouraged to participate and make input.[21] What the results of the present study suggest is the need to broaden and strengthen the participation process to take forward more local and catchment-embedded knowledge in the formulation of the RQOs. If the RQOs reflect more of the local knowledge

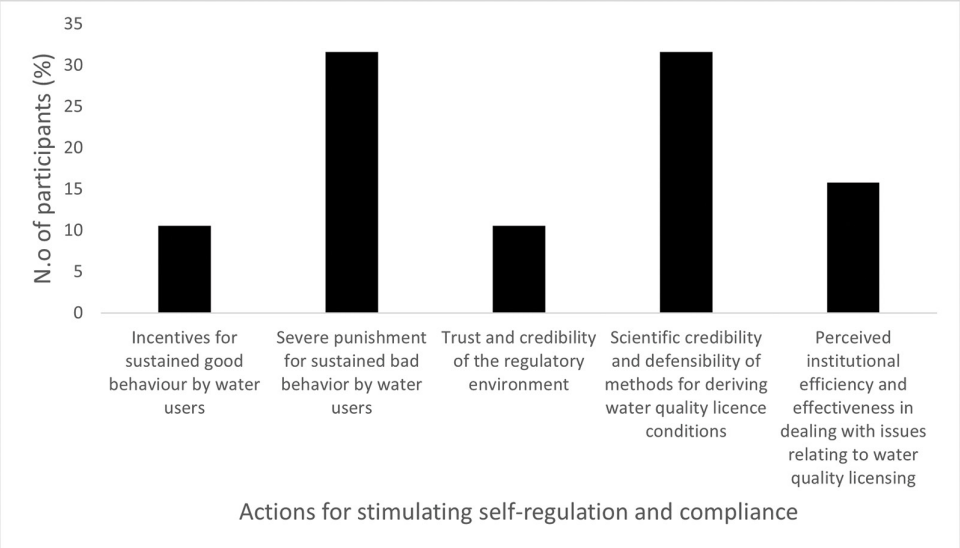


Figure 5: Participants' responses regarding actions necessary to stimulate self-regulation and compliance with water quality standards in water-use licences.

of the catchment, feelings about whether the RQOs are unrealistic may be diminished. The *National Water Act* does not make provision for revising the RQOs after they have been gazetted[29], so contesting gazetted RQOs becomes difficult. The fact that the NWA does not make provision for revising the gazetted RQOs is a weakness that has been identified in the Act.

Scientific credibility improves the legitimacy and reliability of the regulatory environment.[31] Credible scientific measurement is essential to environmental decisions and policies.[32] A study by Odume et al.[14] showed that one of the contested issues associated with water quality regulatory instruments is the perceived lack of scientific credibility and defensibility of the standards in the WULs. In the present study, the credibility and adequacy of scientific data has been raised as a concern regarding both the RQOs and standards in WUL. Berg et al. noted that credible data collection and sharing can foster coordination and build trust.[33] In addition to data adequacy, the participants advanced several reasons why they disputed the scientific credibility of the process of deriving water quality standards in WUL. For example, the participants argued that the links between WUL and RQOs were not clear and that the implications of upstream waste loads on the standards for downstream resources users were also unclear. Given these reasons, it is important that the regulator and resource users embark on an open, transparent process that reassures all stakeholders of the scientific credibility of the methods and processes for arriving at standards in WUL. Such a process can have a positive, reinforcing effect on the regulatory environment.[33]

Compliance with regulatory instruments is necessary to achieve a balance between resource protection and use. Effective compliance could lead to equitable water allocation, improved relationship between users, and a reduction in illegal water use that threatens ecosystems.[34] Within the water sector in South Africa, compliance monitoring is done by institutions such as the Department of Water and Sanitation (DWS), catchment management agencies (CMAs), and regional offices of the DWS. To ensure compliance, a study conducted by Hugo[35] reported the need for a structured criminal penalty system for environmental violations in terms of the *National Water Act, Act No. 36 of 1998*[36]. An effective administrative penalty system could be a solution for ensuring that water users comply with the provision of their WUL. As argued by Hugo[35], such an administrative penalty system for environmental violations would implement punitive measures in the case of non-compliance and provide incentives to encourage compliance.

Punitive measures as a way of stimulating compliance are recognised as calculated motivation.[37] Calculated motivations refer to resource user compliance motivated by the likelihood of fines that are imposed upon violation of the water quality standards in the WUL.[37] A study by Winter and May[37] revealed that the likelihood of detection, the likelihood of a fine, and the cost of compliance are important factors that influence a resource user's decision to comply with the provision of WUL. The likelihood of detection refers to the frequency of inspection, which may lead to the detection of violation, whereas the likelihood of a fine may influence the resource users to comply, particularly if the costs of the fine far exceed that for compliance.[37] The NGO Save our Vaal environment (SAVE) have in the past taken Sasol's coal mining division to court to halt the latter's then plan to commence mining operation on sensitive ecosystems within the Barrage catchment. SAVE won the case, implying that civil society organisation has a critical role to play regarding water quality management.[38] Apart from punitive measures, other mechanisms exist for facilitating and encouraging compliance, such as incentives, education and awareness-raising, self-regulation through ISO, as well as trust and credibility within the regulatory system.

The research participants indicated that education and raising awareness can encourage compliance with the water quality standards in the WUL. Studies such as that undertaken by Okumah et al.[39] have indicated that scientific evidence and raising awareness can influence resource users' actions towards meeting regulatory standards. The study suggests that active awareness-raising and education can result in stakeholders making better, informed decisions.[28]

Conclusion

In this paper, the perception and motivation underpinning water use, and the contestation of relevant regulatory instruments were explored. Perceived unrealistic RQOs, perceived lack of scientific credibility of the methods for deriving water quality standards in WUL, as well as poor institutional capacity were identified as the top motivations for contesting applicable regulatory instruments in the catchment. However, the research participants recognised the importance of water resources within the catchment and the need to heighten compliance levels to protect them. Punitive measures, education, and awareness-raising were identified as key to accelerating compliance. The general implications of the findings in this paper are that (1) there is a need for a multi-pronged approach to increase water quality compliance, (2) there is a need for trust within the regulatory system to increase confidence in the system, (3) there is a need to strengthen institutional capacity both in terms of implementation and costs recovery for services delivered, and (4) transparent, open processes and methods are needed for deriving standards in WUL to assure their credibility and defensibility. Overall, this paper contributes to our general understanding of the intricacies of water quality management within a contested space.

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Data availability

The data supporting the results of this study are available upon request to the corresponding author.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. Ethical clearance was obtained from the Rhodes University Ethics Committee with approval number 2019-0288-693.

Authors' contributions

O.N.O.: Conceptualisation, methodology, data collection, sample analysis, data analysis, validation, writing – the initial draft, writing – revisions, student supervision, project leadership, funding acquisition. A.C.: Data curation, data collection, sample analysis, data analysis, initial draft. C.F.N.: Data analysis, validation, writing – the initial draft, writing – revisions. A.S.: Student supervision, project management, writing – revisions. All authors read and approved the final manuscript.

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Co-creating enduring practitioner-researcher collaborations in multi-functional landscapes

Collaboration between different disciplines, sectors and society is essential to tackle contemporary sustainability problems. This paper integrates learnings and reflections from a series of workshops and interviews conducted in the Berg-Breede landscape that explored the challenges and enablers to long-term, researcher-practitioner partnerships. We found several, often entrenched and systemic, challenges to working collectively and equitably within complex landscape spaces. From conversations on solutions to these hurdles, we distilled out four key enablers of enduring collaboration, drawing on critical moments of learning and understanding and thinking about how the benefits and values of collaboration can be leveraged and amplified. Our work illuminates how supporting enduring collaborations can help bridge the research-implementation gap to facilitate more equitable and resilient multi-functional landscapes.

Significance:

While sustainable and equitable management of landscapes can be improved through intentional efforts to build collaborative partnerships between researchers and practitioners, the longevity and endurance of these partnerships rely on several features, including shifts in the way researchers design and undertake their research, in the values and benefits that collaboration can deliver, and in how research findings are articulated and shared. Third spaces can play an important role in achieving these shifts and enhancing collaboration.

Introduction

Rapid and unprecedented social and environmental change is creating many complex challenges across social-ecological systems globally that hinder achievement of the Sustainable Development Goals.[1,2] Finding solutions to these multifaceted and interconnected challenges requires new, more integrated and collaborative ways of working across sectors, actors and knowledge systems.

Collaboration involves actors from different societal sectors and interest groups working together, sharing risks and challenges, and combining their unique resources, strengths, views, knowledge and competencies to find mutually agreed solutions to pressing societal and environmental concerns.[3] Such collective problem-solving and knowledge co-development can facilitate out-of-the-box thinking; reveal innovative, negotiated and sustainable solutions; and promote equity with regard to the range of views, values and voices that are heard. Meaningful collaboration needs to be well aligned to local concerns and needs; broaden the knowledge base by including scholarly, experiential, tacit, local and Indigenous knowledge; and bring disconnected actors, sectors and government institutions together in pursuit of a common goal.[4] Collaboration can also lead to practice that incorporates new evidence regarding what is needed to change the status quo towards greater sustainability and equity.[5,6]

Engaged sustainability science, transdisciplinary research and implementation science are research approaches that advocate for collaboration between researchers and practitioners, and other relevant stakeholders[7,8] to achieve the above goals. Enhanced relationships between these actors are considered critical for ensuring relevant, action-orientated research that helps to bridge the research-implementation (knowing-doing) gap and inform more sustainable and equitable practice.[9,10]

However, in many situations, including in our case study area – the Berg-Breede landscape in South Africa – there are inadequate connections between researchers and practitioners on an ongoing basis, especially within the context of wider landscape resilience. Landscapes are characterised by overlapping and contested land uses and values requiring negotiation of the trade-offs created by these competing interests, as well as ways to conserve the ecosystems that generate the services that people depend on and may compete over.[11] Collaboration to support sustainable and resilient landscapes therefore needs to focus on multiple landscape concerns (wildfires, water quality, agriculture and food security, conservation, livelihood opportunities, rural-urban development conflicts, etc.), which requires regular dialogue between partners in order to pursue multiple solutions and outcomes (e.g. through co-management, collaborative governance, research and monitoring, regional coordination, equity of benefits and burdens) that build on the best available knowledge.[12]

Given this context, we believe that to address such complex interconnected sustainability concerns at the landscape scale and support new research and action that directly responds to these concerns, collaboration that is based on longer-term partnerships and coordinated and regular interactions is required.[5] However, such collaboration is not easy nor guaranteed to succeed and faces numerous barriers.[5,7] For example, bringing together people from different walks of life, who often hold different worldviews and values, can be complex and potentially fraught if there are power inequities and conflicts over resources between actors. In addition, building the trust, common vision and direction that is needed to overcome these issues takes time and resources.

One approach to facilitate more continuous communication and knowledge co-production is through the establishment of multi-stakeholder platforms or communities of practice (CoP), both of which can be referred

to as 'third spaces' (for example, see Annan-Aggrey et al.[11], Cockburn et al.[5] and Roux et al.[13]). The concept of a third space (used mainly in teacher education) is seen as a metaphor for a process where participants from across traditional boundaries form a partnership to collaborate and co-construct knowledge to improve practice.[14] A third space is an interdependent and relational space that is non-hierarchical and generally has some form of permanence.[10,14] We use the term third space to remain open as to what shape the collaboration might take.

In this paper, we explore what might be needed to facilitate enduring researcher-practitioner collaboration in the Berg-Breede landscape. This landscape is the site of multiple, sometimes overlapping research projects, across different institutions, with many designed to address social-ecological sustainability issues. However, coordination across these institutions and projects is often poor, with patchy involvement of non-academic actors. Moreover, the impact of research on more sustainable landscape management is quite fuzzy, and implementation is not always keeping up with the latest science. Where collaboration has happened, this is usually linked to a single research project and comes to an end once funding has run out. Consequently, we saw an opportunity to learn from practitioners' (individuals from non-governmental organisations [NGOs], local government, provincial departments and conservation organisations; see the supplementary material) and researchers' experiences of research and action in the landscape to inform how collaboration could be improved.

To do this, we initiated a social learning process where we facilitated conversations around participants' experiences of research, research partnerships and participation in multi-stakeholder processes. Specifically, we considered the possibility of a third space for collaboration and the potential enablers that could enhance the long-term sustainability and usefulness of such a space, as well as help overcome some of the challenges and barriers identified.

In the next sections, we commence with a short description of the Berg-Breede landscape context. We then outline the approach and methodology we used in our engaged sharing and learning process, with details available in the supplementary material. From there, we provide a summary of the primary issues that reportedly are impacting negatively on collaboration, and then move to the main findings, which are synthesised and presented as a set of four enablers that are important for enduring partnerships. In presenting and discussing these findings, we also refer to relevant literature.

The case study: The Berg-Breede landscape

The Berg and Breede catchments (hereafter referred to as the Berg-Breede landscape) are located in the Western Cape of South Africa and consist of the Berg catchment to the north and the Breede to the east of the Greater Cape Town area. The landscape is a critical area for water supply to the city of Cape Town, surrounding deciduous fruit farms and wine estates, and residents, as well as being a popular tourist destination. The landscape is under pressure from these multiple demands, as well as rapid land-use change, plant invasions, deteriorating water quality and climate change.[15,16] The region is also characterised by high levels of social inequality. Many pockets of extreme poverty and wealth exist, and the experience of communities in terms of service delivery, participation in the formal economy and in influencing strategic decision-making processes differs widely depending on their socio-economic status. These high levels of inequality make the catchment a challenging area to work in and heightens various ethical and justice issues.

As for other landscapes, government agents, civil society groups and NGOs have responded to the complex challenges of landscape management through the creation of several platforms and networks. These platforms focus on various aspects of landscape management and cover different geographical areas, often related to catchment and subcatchment boundaries (see the supplementary material). However, there is no landscape-level forum that specifically brings practitioners and researchers together to collaborate on interlinked landscape sustainability and equity issues.

Approach and methodology

Our study is based on qualitative narrative data derived from a series of eight (seven online due to COVID-19 restrictions, and one in-person) engaged, learning workshops (see https://sites.google.com/view/berg-breede/home) with different landscape stakeholders (some 30 in total for online workshops and 31 for the in-person engagement), followed by in-depth interviews with selected practitioners (Figure 1).

Workshops were widely advertised through our contacts and networks in the Berg-Breede landscape. All of us had prior involvement in research and practice in this space. The participants who attended the workshops were those who were interested in and signed up to the process. We also encouraged key role-players to invite colleagues whom they thought might be interested in attending.

In the first workshops, we surfaced some of the important challenges to collaboration from the perspectives of both researchers and practitioners, respectively. In the subsequent workshops (again with researchers and practitioners separately), we discussed solutions to the identified barriers, as well as potential enablers of long-term collaboration for engaged transdisciplinary research. In the final in-person workshop, we focused on the possibility of a third space as an avenue for collaboration.

Following this, we undertook six individual semi-structured interviews with practitioners. We recruited participants based on their involvement with existing platforms in the Berg-Breede landscape (see Supplementary table 2). Snowball sampling was employed to contact additional participants. In these conversations, we sought to obtain a fuller and

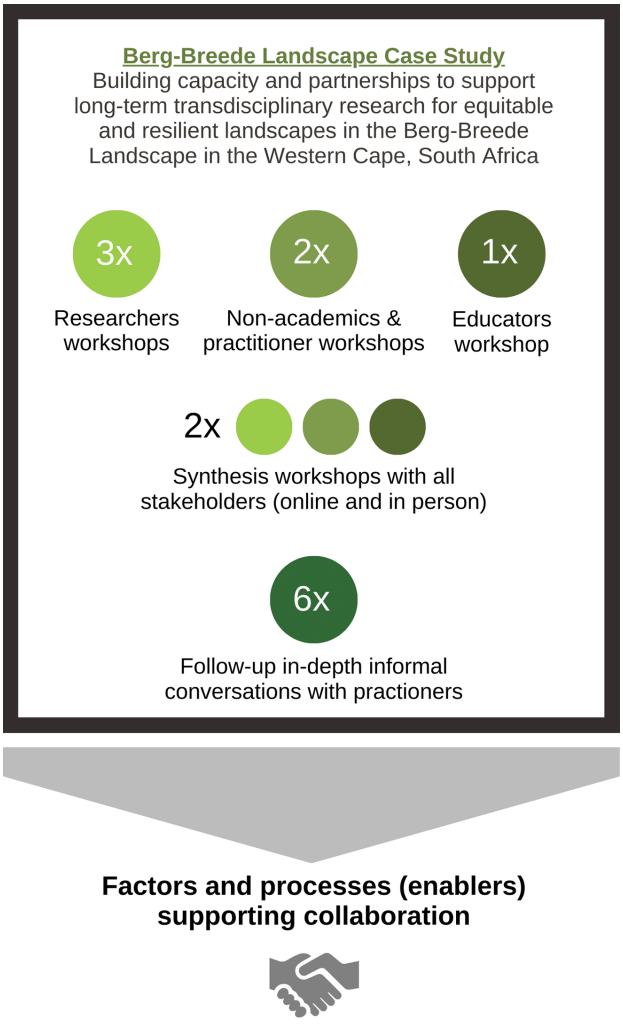

Figure 1: Data collection process using learning workshops and interviews.

more nuanced articulation of the difficulties practitioners face in participating in collaborative efforts and the kinds of values and benefits that would encourage their participation. This methodological approach provided for critical and iterative learning and reflection, from which we were able to distil out key learnings related to what is needed for effective and long-term collaboration between researchers and practitioners. Both the workshops and the interviews were recorded and transcribed. Using our notes and the transcriptions, we spent a day working together as a team to pull out the key insights. For the interviews we undertook thematic analysis using NVivo. More details on the workshops and interviews and their analysis are provided in the supplementary material.

Reflections: What is needed for effective long-term collaboration?

Synthesis of challenges/barriers hindering effective collaboration

During the first workshops on surfacing challenges (adapted from Theory U), conversations revolved around several issues that can negatively affect participation in collaborative research activities and act as barriers to enduring partnerships.

Many of the issues raised could be partly the result of not having an existing means for regular interaction between practitioners and researchers, but also relate to how researchers position themselves and their research, their skills and capacities for engagement, and on having access to adequate funding; a major barrier mentioned by all participants. Inadequate communication, recognised by both groups, was said to result in the duplication of ideas, knowledge and work, placing greater demand on practitioners and leading to research fatigue. Further, it was mentioned how students and researchers are often inadequately prepared and poorly informed on the landscape context and the range of actors involved in landscape management and governance, which can create unintended outcomes that can potentially damage relationships among stakeholders. Researchers mentioned how there is limited training and university support for this type of engaged research, and most researchers "have to find their own way" (discussed further in Shackleton et al.[17]). Poor alignment between research and the knowledge needs of practitioners – something that is touched on in other cases[5,7] – was also highlighted. Practitioners are generally most interested in research that helps them do their jobs better. A lack of reporting back of research findings and follow-up was stressed as also being a demotivating factor and, even when this was done, it was often in ways that were not easily accessible to non-researchers, nor were the practical implications of the research for practitioners' day-to-day work often pointed out. Additionally, a lack of time, funding, mandate and skills to work closely together and difficulties ensuring continuity and sustainability of any collaborative platform were stressed.

Enablers (factors and processes) supporting enduring collaboration

Drawing on the discussions related to what is needed to support collaboration, overcome the barriers mentioned above and establish an effective third space, we distilled out four key enablers, with several subcategories (Figure 2). While a third space is considered critical to bridging the research-implementation gap, the other enablers, which are all closely interconnected, are needed to ensure that such a space endures and fosters long-term collaboration. For each enabler, we propose potential ways forward based on what emerged from the conversations with stakeholders. We do this alongside some of the insights and recommendations from the literature regarding how collaborations can be enhanced and made sustainable.

a) Co-create safe and neutral third spaces for collaboration

Convening neutral third spaces (potentially a combination of digital and in-person meetings) for researcher-practitioner dialogues, relationship building and co-learning was recognised by participants as critical for engaged scholarship and knowledge co-production that focuses on joint problem-solving and actioning of research.[13] Hosting these meetings in neutral venues in the landscape such as schools, community centres or natural areas changes the dynamics and allows stakeholders to connect around mutual concerns, surface and negotiate contentious issues, and move towards collective action to address the multi-faceted challenges faced in the landscape. It was also highlighted in the social learning process that traditional ways of engaging such as sitting around a table talking, no matter how well facilitated, may result in a loss of interest or some people being more comfortable and outspoken than others.

Workshop participants suggested that at times it may be necessary to look for exciting and innovative ways to engage that can also change the power dynamics between stakeholders and open the doors to more creative thinking. For example, one suggestion was organising floating seminars along the Berg River to get people out of their comfort zone and to observe the landscape from another perspective. Other examples mentioned included tours and site visits, demonstration sites and mini conferences with ample social space and activities built in as is the case for the Garden Route Interface and Networking (GRIN) meetings.[13] Regarding the latter, conversations over lunch and tea were mentioned as key to relationship building and cited as a source of new and spontaneous collaborations. However, practitioners shared how they were facing increasing time and resource constraints that can hamper their participation. For regular interaction, online meetings were said to be more easily accessible, require fewer resources to attend and also allow for more focused work to be done. However, for relationship building, it was noted that "nothing beats an in-person meeting". A balance between both would be ideal.

With time, the ambition is that third spaces become long-term platforms that meet on a regular or annual basis, thriving CoPs, or even networks.[5] Participants in the final workshop agreed that a researcher-practitioner collaborative space, perhaps linked to other multi-stakeholder platforms in the Berg-Breede landscape, could be a way forward. They agreed that its function should be to support research on social-ecological sustainability, provide neutral ground for researchers and practitioners to build a shared context on the research needs of the area, facilitate engagement in social learning, co-develop transdisciplinary research projects, build capacity for joint work, and provide a forum to share and explore the implications of research findings. Since the last workshop, the new Cape Floristic Region Partnership (CFRP) has taken on this role. They organised a further researcher-practitioner workshop, created a working group and designed a session for a researcher-practitioner engagement at the annual Fynbos Forum.

b) Enhance the ability and capacity of researchers and practitioners to collaborate

It has already been noted that collaboration can be challenging. Developing a safe, relational and interdependent third space that can build trust and respect among participants requires (self-)awareness of what it means to work collaboratively[10] as well as a set of skills to better navigate the research–practice interface. Collaboration cannot happen without changes in the way both researchers and practitioners approach their work.

Shift ways of working to build trusting and respectful relationships

Researchers often take on multiple roles in third spaces, for example, that of researcher, facilitator and connector. But they are seldom equipped with the necessary skills to do this as these are rarely part of their traditional training. Consequently, researchers may attempt partnerships without the preparation that could enhance the success of collaboration.[7] More 'soft' skills training is required to build confidence in undertaking engaged research, in liaising with practitioners, in facilitating multi-stakeholder spaces and in dealing with trade-offs and conflict.[17,18] In addition, greater (self-)awareness of what it means to work in a relational way is needed among both sets of partners.[10] This means moving from being self-focused and independent to being other-focused and interdependent so partners respect, trust and avoid speaking past one another.[10] A caring and open demeanour, the ability to listen, reflexivity (related to how the process unfolds and of one's own positionality), respect for other knowledge systems, understanding partners' constraints and the ability to negotiate cultural differences, among others, can assist in this. Creating this type of mindfulness can be facilitated through interactive coaching

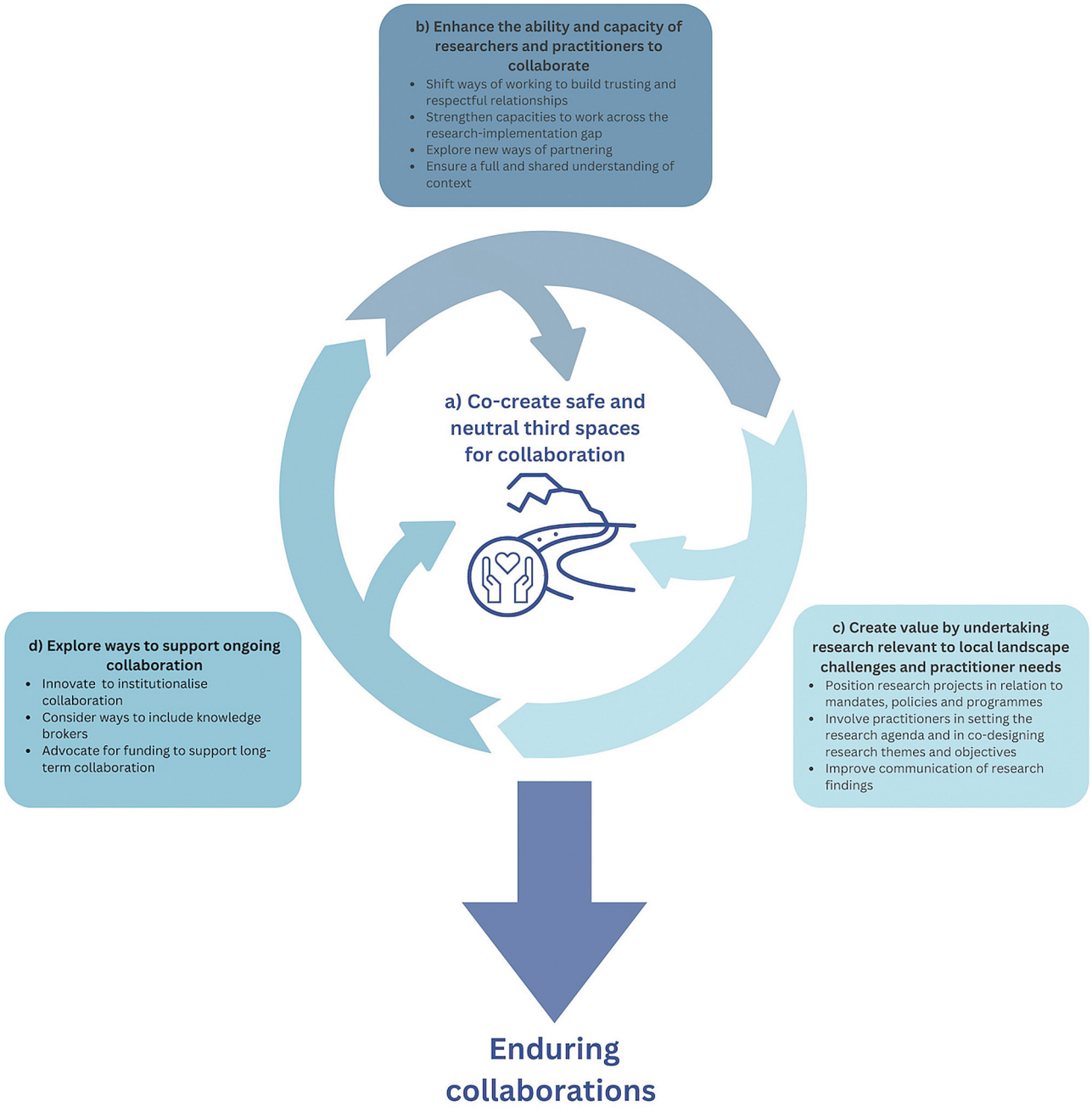

Figure 2: Key enablers supporting enduring collaborations.

and dialogue. That said, it is also important to recognise when an expert neutral facilitator may be needed.[6]

Strengthen capacities to work across the research-implementation gap

Capacity strengthening around how to use evidence in implementation[19] and, conversely, how to produce such evidence, can assist in making collaborations more valuable. It is often unclear to both researchers and practitioners how research results can be effectively translated into action. Frequently, the role of research is quite opaque and indirect, while practitioners are looking for outputs that more directly assist them in their daily work. Capacity strengthening to better understand what is needed by practitioners and how this can be delivered by researchers and then adopted by practitioners could help in producing more actionable science. Researchers need to find ways to generate immediate workable findings rather than waiting until later in the research process, particularly after papers have been published, as is often the case. An example of a capacity strengthening initiative related to this is the evidence-informed policy-making (EIPM) training course offered by the African Institute for Development Policy. Much of the learning can also be related to practice.

Explore new ways of partnering

Another way to address the concern that researchers and practitioners seldom get the opportunity to interact is by engaging with one another beyond the usual roles. This can improve understanding of each other's contexts and ways of working and ultimately lead to deeper and more trusting relationships. This engagement could include involving practitioners as co-teachers in university courses and curriculum processes, involving researchers in community engagement activities and training, embedding researchers in local structures for the duration of their research (e.g. in municipalities or NGOs)[20,21] (see above) or vice versa, and bringing students into service learning in the landscape. Furthermore, practitioners suggested that while undertaking projects, researchers should live in the landscape and engage in various landscape activities to further build trust and relationships. By embedding in the

landscape, it is more possible to continue engagement outside of project cycles and strive for continuity in further research.[22]

Ensure a full and shared understanding of context

It was also pointed out that collaboration can be enhanced by ensuring a common understanding of the context. To explore research options that will provide useful evidence for practitioners, it is necessary to understand the complexities of the context within which the research and implementation will take place, something that can be part of third space discussions. Context is generally understood as the social, political, governance and environmental settings in which the investigated 'real-world' sustainability problems emerge.[22,23] Understanding context requires a holistic approach to identifying the key drivers that shape important local conditions and processes.[22] Joint examination of what research has been done before, including where in the landscape and who was involved is essential. It is also important to explore the perspectives, roles and knowledge of key actors within the landscape, as well as their relationships (with each other, and with the landscape itself). Tools such as stakeholder and power mapping can greatly assist in this.

c) Create value by undertaking research relevant to local landscape challenges and practitioner needs

The points highlighted below are all areas that should be part of the conversations that happen in a third space. If time is given to these, collaboration is more likely to deliver value to partners and be more sustainable. Interviewees who regularly participate in practice-related multi-stakeholder spaces mentioned how important these are for capacitating the next generation of practitioners, for facilitating effective coordination, and for assisting with more efficient use or saving of resources. Researchers and practitioners need to work jointly on providing similar values in their collaborations. Below we highlight some ways to do this.

Position research projects in relation to mandates, policies and programmes

Support for the implementation of policy (i.e. practice) was mentioned by practitioners as more important than creating new policy. Practitioners volunteered that there are many good policies to support sustainability – the challenge is the implementation of these policies compounded by the slowness of the bureaucracy and a range of complex governance issues. It was suggested that researchers should connect with government department staff (practitioners, managers and decision-makers) to understand what the implementation needs are and where the blockages are and then work with stakeholders to understand and tackle these.[24] Odume et al.[25] in research in several African cities, found that 'explicitly conceptualising and communicating research projects in relation to mandates and policies' as well as programmes (including those of NGOs) provided an important pathway for supporting interactions.

Involve practitioners in setting the research agenda and in co-designing research themes and objectives

To improve the relevance and value of research, it is essential to engage with its end users to understand their knowledge needs and priorities. Regularly updated, co-developed research agendas can provide the insights that researchers need to raise appropriate funding, direct researchers to the relevant landscape actors for further discussions and inclusion in proposals, respond timeously to funding calls and identify research projects for postgraduate students. This need for jointly identifying research priorities and questions was highlighted by Cockburn et al.[5] in their work on building a science-action partnership for local land-use planning and management in the city of Durban, South Africa. The authors mention how potential research projects were jointly developed by partners but were driven by the management and decision-making needs of the eThekwini municipality.

Improve communication of research findings

Co-developing knowledge products helps to ensure that they are tailored (e.g. in terms of language, framing, delivery and visuals) to implementation needs. The typical briefs written by researchers do not always gain the traction desired.[26] Increasingly, we are seeing other forms of sharing research findings within collaborative spaces, with boundary organisations, playing a role in this.[27] Work on regional multi-stakeholder landscape platforms in Uganda and Kenya demonstrated clearly how knowledge sharing, usually the first part of any meeting, made a real difference in supporting policy and practice.[3] Another example mentioned were the dialogues at the end of projects funded by the Water Research Commission (South Africa) where critical research findings for enhancing water sustainability are shared with local and national stakeholders. Sharing findings in an accessible way is a key activity that could be coordinated through a third space.

d) Explore ways to support ongoing collaboration

Long-term collaboration cannot happen without funding and coordination support. Stories of failed collaborative efforts were shared in the workshops. Below we explore what could assist in providing stability to a third space as well as adequate funding for coordination, workshops, meetings and other events.

Innovate to institutionalise collaboration

The ability to collaborate is often limited by poor recognition of the value of researcher-practitioner collaborations in the wider workplace, especially in government. This type of collaboration is seldom part of government officials' job description and may not be recognised as legitimate work by their managers. This limits the incentive and ability to collaborate. Greater advocacy of the value of engaging with research is needed in the implementation space.

Furthermore, participants shared that previous efforts to initiate means for researchers and practitioners to collaborate beyond a single project had limited lifespans due to short-term funding and/or the champions leaving (sometimes the result of a lack of funding in soft-funded research or NGO positions). A lack of permanence and the continuity needed to keep relationships going is a persistent barrier that has no simple solution, especially without adequate funding.

Ideally, researcher-practitioner third spaces should be supported by either or both universities (in terms of building partnerships for undertaking research related to these institutions' immediate context) and/or government. Regarding the latter, one problem is the siloed nature of government departments which do not cater for the wide range of linked sustainability challenges that need attention to ensure more equitable and resilient landscapes. However, there are examples of successful government-hosted platforms to address integrated climate change adaptation at both national and local level. In the case study by Acosta et al.[3], the responsibility for collaboration was transferred to government entities (in Tanzania and Uganda) after initiation under a donor-funded project. The authors emphasise that 'embedding the platforms within government structures provided those official bodies with convening power, a greater sense of ownership over the process, and ultimately offered the platforms a pathway to sustainability'. One of our participants mentioned that sometimes all it requires is for collaboration to be seen as a priority by the government leadership. In addition, in the Tanzanian and Ugandan examples described by Acosta et al.[3] meetings happened quarterly and started with the sharing of research and experience, followed by a decision-making process using participatory engagement approaches. The authors highlight how such knowledge sharing helped to build trust, agree on common goals and foster unified action. In another example, the GRIN third space, long-term partnerships and sustainability was achieved by having a champion, who worked for SANParks and was associated with a university, coordinate the annual research and practice meeting with the support of different stakeholders on a rotational basis.[13] To help cover costs, a basic fee was charged for the three-day knowledge sharing get-together.

Consider ways to include knowledge brokers

Knowledge brokers as individuals (also referred to as boundary spanners and facilitators) or in a collaborative third space structure, such as a CoP, platform or boundary organisation, are increasing being recognised

as crucial enablers of effective collaboration and systemic change (an example from the Berg-Breede was the NGO Living Lands which unfortunately is no longer operating).[28] The ideal would be a dedicated coordinator/knowledge broker for the third space structure who could help with synthesising research, matching researchers and practitioners on new projects, facilitating workshops, supporting engaged scholarship, liaising with universities and dealing with administrative needs. Similarly, having knowledge brokers embedded in local universities (such as in their research offices) who could take on similar roles could help close the research-implementation gap. Such knowledge brokers need to communicate in a multilingual, multicultural, multi-level and multidirectional context which requires a specific set of skills and expertise.[6] Specific funding thus is often required for this role as outlined below.

Advocate for funding to support long-term collaboration

We are seeing more national funding for engaged and collaborative research, for example, through initiatives like the Expanded Freshwater and Terrestrial Environmental Observation Network (EFTEON), but often funding does not include resources to build the relationships needed within the lifetime of the project, never mind supporting the actioning of the knowledge generated. For research to have an impact, longer-term collaboration beyond single projects is needed to solidify relationships, enable project findings to be properly synthesised, communicated, and acted on, and ensure some continuity between projects.[29] Furthermore, at a landscape level, integration and understanding across different research projects is needed to address complex sustainability challenges. Funders interested in impactful research should think beyond funding only projects or researchers and boost the continuity of engaged work by valuing and financing brokers as well as the collaborative spaces that are needed for building resilient and equitable landscapes. In addition, universities should consider hiring knowledge brokers to serve as central points of contact for all researchers and practitioners working within the greater university space.

Conclusion

The findings from this case study show that building enduring partnerships between researchers and practitioners is not easy as there are multiple hurdles to effective collaboration. For example, it requires adequate and sustained funding to support ongoing collaboration through third spaces. It is also critical that stakeholders have the time to engage, especially given the often-slow process of knowledge co-production and translation of findings into action. In addition, collaborative activities need to be included in practitioners' job descriptions and be seen as legitimate work. Similarly, university and research institutions need to make working with external partners part of a broader strategy to support decolonised research and to respond to local sustainability concerns. Third spaces need the wide support of not just participants but also those to whom these stakeholders are accountable. The interactions between partners need to be respectful and produce real benefits that go beyond learning to actions that improve landscape equity and sustainability. Practitioners need tangible results for their time. The four enablers of collaboration outlined in this paper provide some insights on how to do this. They have been helpful in guiding the CFRP with their initiative for researcher-practitioner collaboration in the Berg-Breede landscape, as well as in the NASA-funded BioSCape project.[30]

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Data availability

The data supporting the results of this study have not been made available by the authors in any format.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. Both the workshop series and interviews were approved by the UCT Science Faculty Ethics Committee (Workshops: FSREC 036-2021; Interviews: FSREC 073-2023).

Authors' contributions

S.S.: Project leadership, funding acquisition, conceptualisation, data collection, data analysis, writing – the initial draft, writing revisions. P.d.P.: Data collection, data analysis, writing – initial draft, writing revisions. N.S.: Conceptualisation, data collection, data analysis, writing revisions. C.F.: Data collection, data analysis, writing revisions. N.M.: Conceptualisation, data collection, data analysis.

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Local and national stakeholders collaborate to take on *Prosopis* invasions with biological control and biomass use in South Africa

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Research that directs the way stakeholders act and how they collaborate is essential when addressing complex environmental challenges in the field of sustainability science. For example, researchers attempting to manage *Prosopis* invasions through biological control in South Africa have historically faced challenges from stakeholders. In this study, we illustrate the importance of stakeholder engagement and social learning by outlining the collaborative efforts of various stakeholders to promote effective, integrative and sustainable management of *Prosopis* invasions in the Northern Cape, South Africa. Through a community of practice approach, stakeholders worked together over the past half-decade in an attempt to develop a National Strategy for *Prosopis* management and improve its control. This strategy aimed not only to emphasise the need for integration of biomass use (aimed at offsetting the costs of mechanical clearing and necessary herbicide use) but also to underscore the significance of biocontrol alongside other management approaches. Stakeholders also identified that adequate farm-scale planning is necessary to provide a sense of purpose and assist in monitoring of progress. We worked alongside land managers and experts to develop such plans. The engagement of local champions played a crucial role in facilitating collaboration and learning among stakeholders, emphasising the significance of inclusive approaches in addressing complex sustainability challenges. In addition, we gained an understanding of how to develop the community of practice to enhance collaboration that ensures the implementation of plans to better manage *Prosopis.* Our findings underscore the necessity of meaningful stakeholder engagement and collaboration in effective invasive species management. By promoting understanding and involvement of diverse stakeholders, initiatives can have a greater impact in addressing broader sustainability issues.

Significance:

Our findings highlight the fundamental role of stakeholder collaboration in addressing environmental challenges (e.g. biological invasions), promoting sustainability and fostering social learning. Collaboration facilitates exchange of knowledge, promotes social learning and allows stakeholders to make informed decisions when addressing sustainability issues. Collaborative approaches promote the effectiveness of a community of practice in managing *Prosopis* invasions in South Africa. Local champions played a pivotal role in facilitating collaboration, bridging communication gaps and promoting inclusive approaches. Sustained stakeholder engagement, transdisciplinary collaborations, effective biological control and market development for biomass products will be essential to improve the sustainable management of *Prosopis*.

Introduction

To address sustainability issues through science, Brandt et al.[1] stress the importance of transformative research and collaboration. This includes promoting stakeholder engagement in co-design and co-management of action-orientated research as well as social learning.[2-4] Collaboration is needed in all domains of environmental management and conservation, including forestry and agroforestry, but many challenges remain in integrating collaborations and sustainable practices.[5]

Collaborative research is, however, challenging, and there is a risk that stakeholders might feel like subjects rather than true collaborators, leading to potential conflicts. This is common in invasion science[6], and in particular, the management of invasive plants arising from forestry and agroforestry practices, such as *Prosopis* species[7,8]. For example, in South Africa, Harding[9] and Shackleton et al.[10] surveyed landowners' opinions about *Prosopis* management but lacked consideration of other stakeholders and did not offer avenues of more collaborative processes moving forward. They merely consulted local actors through one-way dialogues which had limited effects on social learning and the initiation of actions to sustainably control *Prosopis*. Poor collaboration has likely allowed invasions to spread and impacts to continue to rise, and steps need to be taken to correct this. This disconnect between stakeholders, research and implementation[11] is well illustrated by the biocontrol community's response to the Harding[9] study. The majority of landowners favoured removal of *Prosopis* and more effective management thereof[9], but researchers, in order to avoid perceived conflicts of interest, focused their efforts on seed-eating weevils and, initially, did not consider natural enemies that damage seedlings or the whole plant. Similarly, Shackleton et al.[12] published co-created guidelines for *Prosopis* management in the peer-reviewed literature (a process driven by scientists), which have not been implemented. A reason for this was that there were not, and still are not, processes in place to ensure that government officials and other relevant stakeholders consider or implement the findings of the research (in many cases, such work is even sponsored by government departments but never adequately considered or acted upon). In an effort to make research findings more accessible, the biological control research community provides annual reports on the progress of government-funded projects

to officials and managers who occasionally attend annual research meetings. These awareness-raising and capacity-building efforts appear insufficient to make findings and recommendations accessible to managers and policymakers.

When managing invasive species through collaboration, it is essential to recognise complexities, like different needs and conflicts, and the legal frameworks.[8] For example, in South Africa, legislatively the onus of invasive species management, including *Prosopis*, is on private landowners[13], but the government is responsible for public areas and communal lands. Despite government efforts, such as the Working for Water (WfW) programme, allocating substantial funds to manage invasive species on public and private lands, the effectiveness of management remains limited, with WfW targeting only 4% of the area invaded by *Prosopis.*[14] Scientists attribute this failure to various factors, including a lack of prioritisation, misguided success metrics and insufficient funding. Overall, one option to encourage the sustainable management of *Prosopis* and other plant invasions in the country is to promote collaboration and introduce integrated management, including the introduction of biological control agents.[15,16] However, this has at times been controversial, suffers from funding issues and requires coordination among stakeholders[17,18].

Management of invasions using biological control may be slow and sometimes less effective than expected; therefore, the biocontrol community has legitimate concerns about managing the expectations of stakeholders.[19,20] These concerns should, however, not hinder mutually beneficial relationships between land managers (responsible for the control of *Prosopis*), landowners, biological controllers or other relevant stakeholders. Ultimately, it is necessary to develop partnerships, which will ensure a virtuous cycle of information sharing between farmers, researchers and managers. An effective way of supporting such collaborations and expansive learning between relevant stakeholders is through an insider interventionist researcher who links communities to information[21]; this person can also act as a champion for collective learning[22]. However, this is not always easy to do.

This paper explores our efforts over the past half-decade to establish a community of practice that engages different stakeholders in partnerships to achieve the goal of effective management of *Prosopis* invasions in the Northern Cape, South Africa (see Box 1). We review the process followed, the promising outcomes and developments as well as some key successes and challenges faced.

Box 1: *Prosopis* species found in South Africa[23]

- *Prosopis chilensis* (Molina) Stuntz[9] – naturalised, may form hybrids
- *Prosopis glandulosa* J. Torrey [24]
- *Prosopis glandulosa* var. *glandulosa* J. Torrey[9,24] – naturalised
- *Prosopis glandulosa* var. *torreyana* (L. Benson) M.C. Johnston[9,24] – most problematic, forms hybrids readily
- *Prosopis juliflora* (Swartz) DC[9] – naturalised
- *Prosopis pubescens* Benth.[9,24] – naturalised
- *Prosopis tamarugo* F. Philippi[25]
- *Prosopis velutina* Wootan[9,24] – most problematic, forms hybrids readily

Prosopis invasions: History and management

Numerous species from the genus *Prosopis* were introduced from the Americas into arid regions of South Africa in the late 1800s to act as fodder, shade and fuelwood trees.[23-25] These *Prosopis* species, and hybrids thereof[23], are now invasive in arid areas of the country, with several negative social-ecological impacts[26-33]. Like many useful invasive species, during the early stages post-introduction, the benefits of *Prosopis* were positive, and increased initially.[7,26] However, once *Prosopis* populations got too dense, the supply of benefits dwindled and negative impacts arose. Ecological impacts of *Prosopis* invasions include reductions in insect, bird and plant diversity[27-29], increased mortality of native tree species[30], loss of scarce groundwater resources and grazing potential[31,32]. Social impacts include negative effects on local economies[26] and people's livelihoods[29,33]. With time, the net value of the *Prosopis* trees in South Africa becomes negative as the cost of managing the invasion and its negative impacts far outweigh any positive values. With the fall of benefits and rise in costs, most landowners in the Northern Cape now perceive the cost of *Prosopis* invasions outstrips the benefits of the plant.[10] Due to increased impacts and loss of benefits, many countries globally, including South Africa, are regulating and managing *Prosopis* invasions using various methods.[34-36]

Prosopis management in South Africa has initiated interactions between government officials, forestry and agricultural researchers, and landowners from the time of the first introduction of the species to the present. Between 1880 and 1960, the community was focused on establishing *Prosopis* populations (Figure 1) as forestry officials facilitated the planting of *Prosopis* on private and public land. Essentially, there was a 'community of practice' that worked together to promote *Prosopis* in arid areas. Van den Berg et al.[37] estimated that by 1974, *Prosopis* infested up to 127 thousand hectares in the Northern Cape Province (Figure 1).

Between 1960 and 1987, a new 'community of practice' took shape to understand the extent of unwanted *Prosopis* invasions and how best to manage the growing problem (Figure 1), of which biological control was considered the most sustainable solution. Biological control researchers in South Africa discussed the status of *Prosopis* at their annual research meetings and agreed that a researcher visit the Northern Cape to '*gauge the pest status of the species*'[38]. In order to understand the issue better, Harding[9] surveyed 175 landowners' opinions about *Prosopis* control. There was a strong response in favour of control of *Prosopis* with 51% calling for eradication and 24% suggesting a level of management to prevent further impact[9,23]. Even with this show of support for eradication, the research community 'erred on the side of caution' and chose to focus on biological control agents that damaged dry seeds in an attempt to reduce germination and did not consider natural enemies that might damage vegetative parts of the plants and kill either seedlings or adults. We might consider this a 'failure' of the community of practice at the time as researchers 'chose' to act contrary to the expressed view of the landowners (the most important and legitimate stakeholders). In all likelihood, the approach adopted by biological control researchers was motivated by the paper, 'Tactics for Evading Conflicts in the Biological Control of South African Weeds'[38,39]. This motivates for selection of a biological control agent that could reduce the spread of the plant but protect the pods used as animal fodder.[23,39] In 1987, after thorough research to confirm that three species of weevils (*Algarobius prosopis* (LeConte), *A. bottimeri* Kingsolver and *Neltumius arizonensis* (Schaeffer)) ate only seeds of *Prosopis*, managers released these weevils in large numbers across the Northern Cape. It was found that weevils could destroy up to 92% of seeds in ideal environmental conditions, but the 8% of seed remaining in the environment continued the spread of *Prosopis*.

From 1988 to 2002, the community gained insights into the impact of biological control and considered other approaches for the management of *Prosopis* (Figure 1). Even though the seed-feeding biological control agents appeared to be failing to halt the spread of *Prosopis*, there was an optimistic outlook for its management, a 2001 workshop proposed, that: '*in 20 years from now, invasive Prosopis in Southern Africa will be under control and confined to areas where it can be managed to deliver sustainable benefits*'[40]. Unfortunately, 23 years on, the optimism of this workshop has not delivered this vision; despite much further work, South Africa is far from reaching the goal of having *Prosopis* under control, and currently, invasions are estimated to be over 6 million hectares.

Establishing a collaborative *Prosopis* management initiative

In July 2018, researchers from the Agricultural Research Council – Plant Health and Protection and the Centre for Biological Control (CBC) met with the Natural Resources Management Committee of Agri Noord-Kaap (Figure 2). At this meeting, the biological controllers presented information

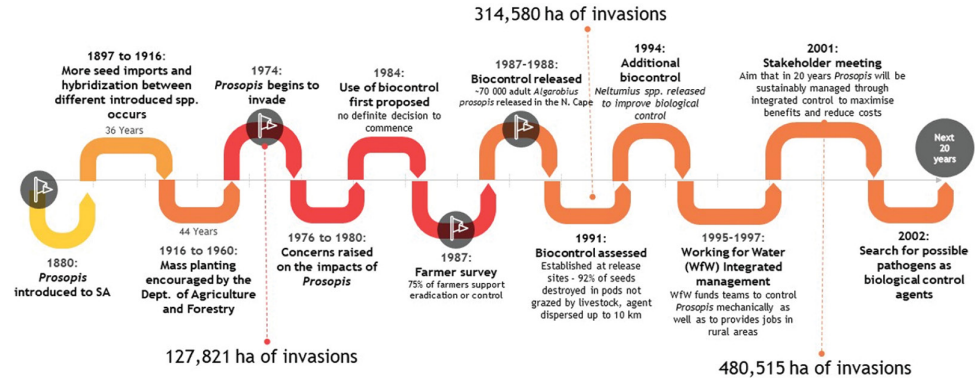


Figure 1: A visual description of the history of *Prosopis* in South Africa (1880–2002). Data were drawn from different sources referenced in the text and from notes of biological control meetings held during the period 1976–2002. The extent of *Prosopis* invasion as estimated by van den Bergh et al.[35] appears in 'ha of invasion'.

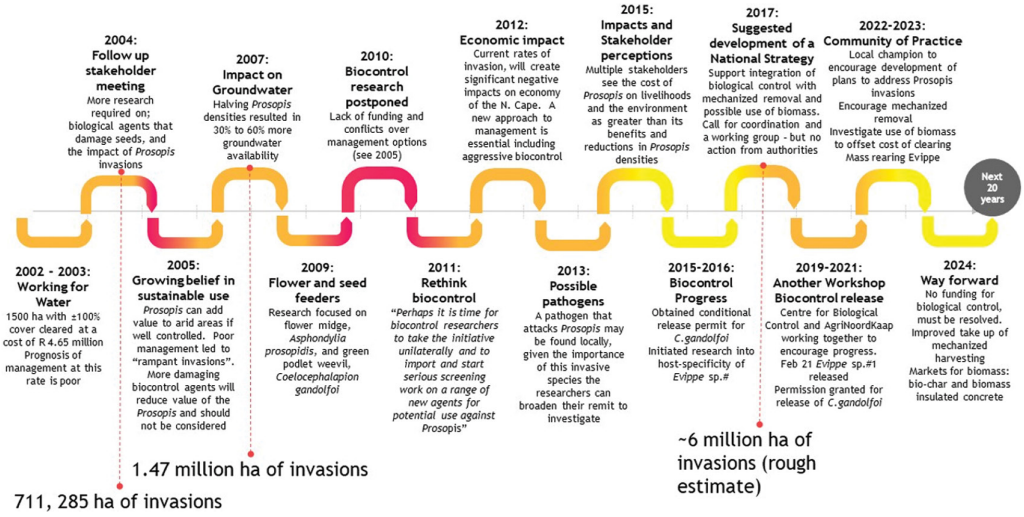


Figure 2: A visual description of the history of *Prosopis* in South Africa (2002–2024).

on the management of both *Prosopis* and cacti. After this initial meeting, Agri Noord-Kaap, in partnership with the CBC, co-ordinated and facilitated a workshop to discuss *Prosopis* management in February 2019. At this meeting, stakeholders from multiple backgrounds and institutions formed a working group to develop 'A National Strategy for Management of *Prosopis*'. Participants at the meeting developed the ultimate goal of promoting sustainable management of invasive *Prosopis* to protect lives, livelihoods and biodiversity. The partnership developed several drafts of the National Strategy, but there were numerous reasons why it went no further: COVID, drought, fire, locusts and the threat of land expropriation without compensation preoccupied many important stakeholders' minds more than the need to manage *Prosopis*. In 2021 and 2022, to promote momentum, champions focused on promoting further collaboration and learning initiatives.[22] In particular, a young researcher originating from a Northern Cape farming community co-ordinated awareness-raising initiatives and sustained interactions between different stakeholders. At a workshop in June 2022, farmers raised concern that the focus of management was too biased towards biological control, '*Ons het vergaderings, en jy bring net goggas en nog goggas*' (We have meetings and you just bring bugs and more bugs). In response to this, a roadshow was arranged (October–November 2022) where experts presented on invasive plant management, biomass use and use of *Prosopis* pods. The content from these roadshows was well received and slowly cooperation improved. The primary local 'champion' has now moved on, but the established networks and relationships continue, and new leaders in the collaborative network have taken up tasks.

Promoting sustainable *Prosopis* management

Through a series of meetings and workshops involving numerous stakeholder groups, we explored intermediate and final goals, including behaviour changes and actions required to achieve 'the Sustainable management of invasive *Prosopis* to protect lives, livelihoods and biodiversity' (Figure 3). We explore these intermediate outcomes below.

Farm-scale plans for *Prosopis* management

The proposed National Strategy for *Prosopis* management[12] which was co-developed by stakeholders from various backgrounds recommended the development of a manual for private landowners outlining best practices for farm-scale management of *Prosopis*. This was important to promote local support, which was necessary to effectively manage *Prosopis* invasions. Subsequent to the 2019 stakeholder meeting, the working group considered this and proposed targets for farm-scale plans:

- Engage experts to develop a template for *Prosopis* management plans.
- Encourage each landowner to produce a management plan.
- Aim for 300 plans by December 2025.
- Encourage 300 plans annually thereafter.
- Encourage landowners from adjacent farms to work concurrently to enable expert to visit groups of farmers at one time.
- All 3600 Agri Noord-Kaap registered farmers to have plans in 12 years.

To achieve the proposed targets, the CBC engaged a private company to develop a template and work with 30 farmers, to prepare plans that included not only an emphasis on biological control but also guidance on herbicide use and post-clearing follow-up (company's expert knowledge). Despite the development of the template and promotional roadshows in October and November 2022, attracting over 150 stakeholders, farmer

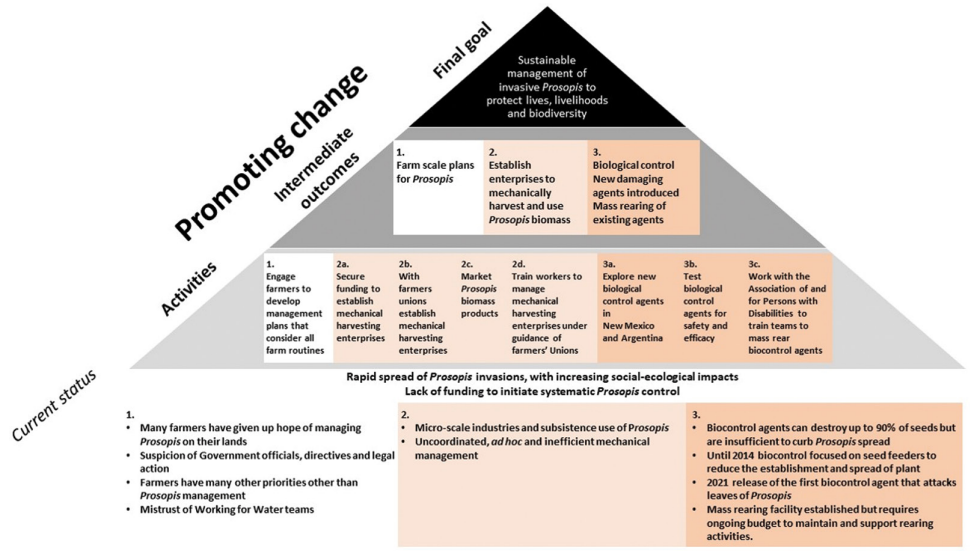


Figure 3: Changes in behaviour and actions required to reach the final goal of 'Sustainable management of *Prosopis* to protect lives, livelihoods and biodiversity'.

responses to date have been low, suggesting that despite successful awareness raising and outreach at the time, behaviour change and acceptance of a different approach can be challenging. In February 2023, the consultancy company that developed the plan reported that they, were '*battling to get farmers to come forward and join for management plans to be drawn up for their property*'. They attributed these challenges to the following factors: (i) farmers fear that a management plan of this nature would lead to the Department of Forestry, Fisheries and the Environment issuing 'directives' that force them to clear their land or face legal proceedings, and (ii) some farmers have a lack of knowledge of, and fear of, technology, which hampers their use of tools such as Google Earth to map the populations of invasive alien plants on their properties. This highlights the importance of ensuring trust, clarity and transparency as well as inclusivity by ensuring the accessibility of tools and technologies and knowledge for all when developing collaborative environmental management initiatives.

To this end, 13 farms were selected for the development or review of their invasive species management plans: three in the Groblershoop area (owned by a single family), two in the Carnarvon area and eight farms in the Brandvlei area. In order to encourage more farmers to make use of the offer of assistance to develop and review plans, we circulated messages on community communication groups, after which a further nine farmers from various parts of the Northern Cape indicated an interest in the development of plans. Of these, four were able to host a visit from the consultant during April 2023. The following useful insights have been gained to date:

- Farmers focus on dense stands of *Prosopis*, feeling helpless. As such, we need to change mindsets to start small and grow with time and show examples that exist where dense invasions have been removed and emphasising the benefits of clearing less dense infestations first.
- There are negative perceptions of WfW's effectiveness (poor work ethic, long travelling times that limit the number of hours of effective work on site and these, at the hottest part of the day). As such, better strategies should be developed collaboratively between farmers and government-managed programmes to improve efficiency.
- Choice of what herbicide to use is sometimes poor and based on what is already available on the farm or the WfW store and not what is most effective.
- The available labour force on farms is low and limits the ability for physical control. This supports the need for better biological control initiatives.
- A 9-year drought has had major impacts on grazing and farmers' finances to fund control initiatives. This highlights that plans need to be cost-effective and adaptive when other priorities become more important.
- The value of land (ZAR300–ZAR1000/ha) is lower than the mean costs of *Prosopis* management (≥ R6000/ha). As a result, farmers are not inclined to invest in clearing *Prosopis* and will rent land for grazing rather than address the invasion. This suggests that cost-effective strategies such as biological control or cost-saving/mitigation strategies are needed (e.g. use of biomass).

Options for management

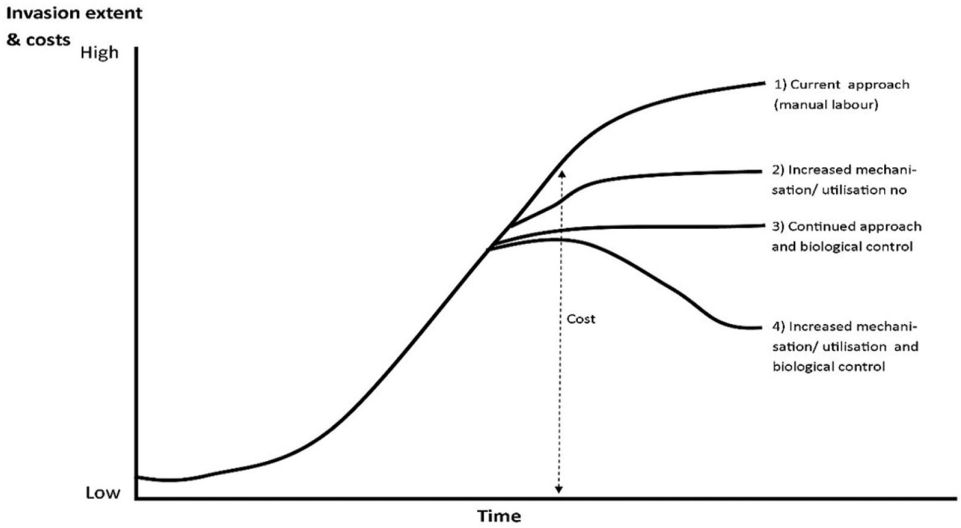
Effective management strategies are crucial to reduce the impacts of *Prosopis* invasions, and integrated approaches are likely to achieve the best results. Based on previous collaborative work and the opinions of stakeholders at a facilitated workshop, we consider four different scenarios[12] (Figure 4):

- Current approach: Maintaining the status quo (uncoordinated manual clearing) would lead to increased invasion extent and management costs.
- Increased mechanisation: Enhancing mechanical control and the use or sale of biomass to manufacture higher value products to offset costs.
- Biological control: Investigating and introducing biological control agents that damage plants and not only seeds.
- An integrated approach: Integrating increased mechanisation, use of *Prosopis* biomass and employing more damaging biological control agents together.

While efforts in Kenya to limit *Prosopis* spread through utilisation have not been effective[36], South Africa's unique context, including landownership and an existing biological control programme, suggests that the fourth scenario, with careful planning and effective biological control, could potentially curb *Prosopis* spread.

Mechanical harvesting and utilisation of biomass

The cost of clearing *Prosopis* trees is high, so the working group investigated options to utilise biomass to cover the costs of control. Marais et al.[41] estimated that the initial clearing of *Prosopis* cost on average ZAR1730/ha. Almost two decades later, Shackleton et al.[12]



Source: Shackleton et al.[12] (reproduced with permission)

Figure 4: Scenarios of the potential extent of *Prosopis* invasion and associated costs over time based on different control options, combinations of options and their potential effects on invasion extent.

estimated the costs of labour-intensive clearing with chain saws and brush cutters to be ~ZAR9000/ha and the costs of mechanised clearing to be ~ZAR10 000/ha. A way of 'subsidising' these costs through potentially using biomass is needed. There might be competing interests between those who have developed income-generating industries around the exploitation of a resource[42], such as *Prosopis*, which land managers want to remove from the landscape. The greatest benefit of *Prosopis* management is the restoration of access to groundwater and grazing and not any income generated from use of the biomass. Therefore, restoration of ecological infrastructure is the ultimate aim of *Prosopis* management, and utilisation is a means to minimise initial costs. Furthermore, encroaching indigenous tree species such as Swarthaak, *Senegalia mellifera* (M. Vahl) Seigler & Ebinger has impacted the quality of grazing and can potentially provide biomass to ensure the sustainability of biomass businesses.[43] The working group identified several possible uses of *Prosopis* biomass, including firewood, charcoal/briquettes, biogas and biomass-insulated concrete materials.

Firewood: Farm managers believe the market for firewood from *Prosopis* to be saturated and that many users prefer to use wood from indigenous trees.[33] The costs of both production (controlling *Prosopis* and preparing firewood) and transporting firewood to market makes this use of biomass uneconomical.

Charcoal and briquettes: Low-input technology (200-litre iron drums) can produce charcoal from *Prosopis* that is suitable for restaurant's barbeque fires and pizza ovens. If there is a local market and other activities carry the cost of transport, then production of charcoal may defray some of the expense of *Prosopis* control. For example, over four months, the cost of managing *Prosopis* and producing the charcoal was ZAR120 000, and the income was ZAR60 000 for 7200 kg, thus covering half of control costs. Charcoal production results in smaller pieces that the farmer cannot sell. One option is to manufacture briquettes from these pieces, but this requires special machinery.

Boskos fodder: To manufacture a cost-effective and abundant fodder, some farmers mill *Prosopis* leaves and branches to which they add sources of protein and energy as necessary. This allows farmers to address the specific nutritional needs of their livestock. This fodder source is both economical and readily accessible and offers a solution for emergencies such as droughts or providing sustenance to animals after wildfires, when natural grazing is scarce. Fodder 'recipes' must comply with current legislation and must be registered accordingly. Further research is required to determine the feed composition for different seasons to ensure consistent nutritional values, and this presents a further avenue for collaboration between academics and farmers moving forward.

Biogas: Engineers have investigated the production of biogas from *Prosopis*. While the technology is currently unproven, it has the potential to supply both heat and electricity for agro-industrial processes (possibly even for export to Europe). This form of electricity generation is appealing given the uncertainty of electricity supply from the national grid. Again, more collaborative and transdisciplinary work is needed on this.

Biomass-insulated concrete construction: This approach aims to improve the thermal and noise insulation qualities of buildings, replace sand and stone aggregate with biomass (possibly invasive alien plants) and reduce greenhouse gas emissions from the combustion of biomass by fixing carbon in building structures.[44] Researchers combined fine biomass chips with fly ash, cement and chemical binders to prepare a sample, which proved that *Prosopis* is acceptable for biomass-insulated concrete construction. The CBC and the Association of and for Persons with Disabilities (APD) required an office and a store at the biological control mass-rearing facility in Upington, which were built using *Prosopis* biomass-insulated concrete techniques (Figure 5). Relevant stakeholders can see this construction technique by visiting these two units. By creating a market for this construction method, farmers will be able 'sell' *Prosopis* biomass to construction companies, enabling them to get some reimbursement for the control costs.

Biological control research and implementation

A core avenue for management identified in the collaborative workshops was the use of biological control.[12] This approach has caused controversy that has limited its use, as *Prosopis* was seen as beneficial by some landowners in the 1980s.[9,45] As such, only agents that ensured the continued supply of *Prosopis* benefits (fuel/fodder) were considered. In 1984, the Plant Protection Research Institute initiated research to introduce seed-feeding insects that are specific to *Prosopis*. After extensive testing of the host-specificity of *Algarobius prosopis* (60 different species of legumes were tested), the government authorities deemed this species safe for release in South Africa.[23] Even though this seed-feeding agent can destroy up to 92% of seeds under optimal conditions, and is able to spread rapidly[23], it is estimated that the size of the *Prosopis* invasion continued to grow from 127 000 ha in 1974 to over 314 000 ha in 1990[37] (Figure 1).

Between 1999 and 2011, the biocontrol community restricted research to two species of natural enemy, one that damaged flower buds (*Asphondylia prosopidis*) and the other that targeted seeds in the green pods (*Coelocephalapion gandolfoi*) (Figure 2).[46] From 2014, biocontrol

research began on natural enemies that damaged the whole plant with research into the suitability of *Evippe* sp. #1 for South African release.[47] The aim of biological control of *Prosopis* is not to eradicate but to reduce the density, spread and impact over time, to a level at which the plants do not have a significant negative impact on the environment (Figure 6). In September 2020, the Department of Agriculture granted permission for the release of *Evippe* sp. #1, and the first releases were made in February 2021. Likewise, in 2019, researchers completed the final testing required for the release of *C. gandolfoi.* Finally in November 2021, with the help of farmers who found sites with *Prosopis* that had suitable green pods, *C. gandolfoi* was released.

After the Department of Agriculture granted permission to release additional biocontrol agents, mechanisms to promote equity inclusion and social justice in the programme were also considered. There are extremely few work opportunities for the approximately 45 000 persons with disabilities in the Northern Cape.[48] Much of the population of this region is rural, and this can further entrench persons with disabilities in poverty, as transport distances and costs restrict access to work opportunities and health care.[49] To this end, the CBC engaged organisations (particularly the APD) that support persons with disabilities and those living in poverty to see if the rearing of biological control agents could be an avenue to create meaningful work for them[50,51] and work towards the goals of the APD, which is to empower, uplift and assist the disabled person in such a manner that they will be able to function independently and earn their own income or at least have funds supplementary to their social grant. The CBC further has collaborated academically with biokineticists to develop biocontrol facilities that provide suitable work environments for persons with disabilities.[52]

With co-funding from the Department of Forestry, Fisheries and the Environment and private entities, the CBC and APD erected a mass-rearing nursery tunnel, offices, storeroom and ablution facilities (all with wheel chair access) at the APD premises in Upington and a team including persons with disabilities has been created (Figure 7). Long-term funding remains essential for this project to succeed, and funding from different sources is vital, as central government funds appear unreliable. Without sponsorship, it would be impossible for APD to provide services and help or assistance to the members of the workshop. This highlights the importance of sustained co-funding to ensure the success of early investments and the sustainability of the whole programme.

Figure 5: Clockwise from top left. *Prosopis* invasion in Groblershoop area, illustrating absence of grass and shrubs for grazing, felled biomass, biomass chips for biomass-insulated concrete construction, different aggregates in 'concrete', *Prosopis* biomass building in Cape Town and completed buildings made from *Prosopis* biomass-insulated concrete at APD Upington.

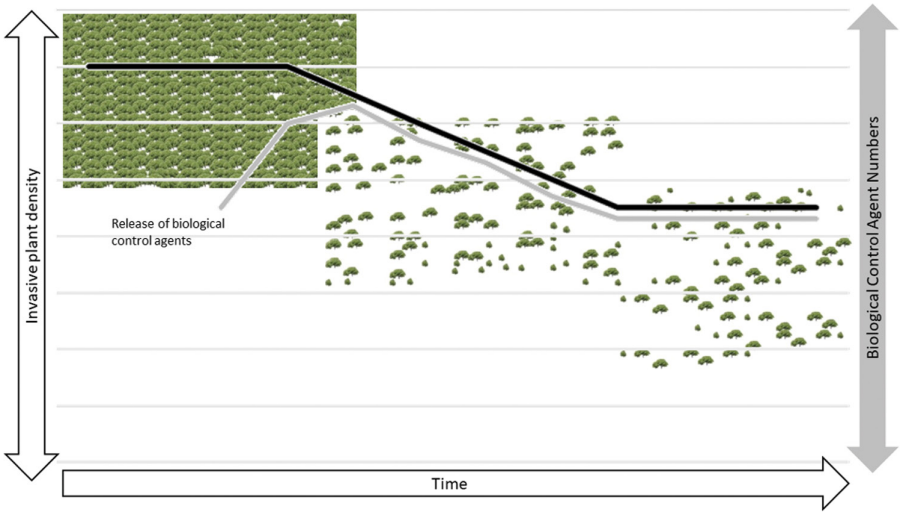


Figure 6: The desired outcome of biological control of *Prosopis* over time.

Figure 7: Training day: Hennie le Roux, Montell Solomon, Anika Coetzee, Steven Sifumba, Johnie Jafta, Rebecca Saulse, Geraldine du Raan, Erin-Pearl Tyers, Corné le Roux, Christopher Strauss, Vuyani Ntlanganiso, Katrina Maklaro, Thabelo Khoele and Philip Ivey.

Discussion and way forward

It remains essential to establish meaningful engagement, co-management and learning, and reduce research-implementation gaps to ensure the successful management of biological invasions.[8,11,53] With regards to the management of *Prosopis* in South Africa in the past, there has been some engagement[12], but the continuity has been lacking, and most research to date has rather treated people as research subjects[10] and not collaborators working together to address shared problems. Realising these past limitations, the CBC has aimed to promote collaborative research and management for *Prosopis* over the past half a decade. Since 2019, the collaboration among stakeholders for the management of *Prosopis* has made good progress. On reflection, the following lessons have been learnt through the process:

- Finding an initial champion to act as an insider researcher and lead collective learning in the Northern Cape community, which has a small number of people spread over a large area, was challenging, but it helped us progress. Forming this community of practice, through the identified champion, better enabled stakeholders (including farmers and researchers) to communicate with one another and share challenges, which has been extremely beneficial. In addition, this collaboration has led to the emergence of new champions in different institutions, which has and will promote continued collaboration into the future.
- Stakeholders are keen to better manage *Prosopis* on their properties but are overwhelmed by the problem and often have more important farming issues to address, even though *Prosopis* invasion can destroy livelihoods if not addressed. Finding adaptable methods to manage multiple stressors simultaneously was identified by stakeholders as a key entry point to promote sustainable management.
- The management planning approach collaboratively developed by scientific experts and land owner experiences aims to make the farm more manageable by focusing operations to open roads, water points and fences, and then to target areas where success can be achieved. Success in this has been demonstrated and promoted in workshops and roadshows to help landowners overcome a sense of helplessness. Although awareness has been raised, more work is needed to promote buy-in and behaviour change and for landowners to adopt and implement plans.
- Through engagement and social learning processes, biocontrol is now better understood and accepted by the stakeholders. This is best illustrated by the assistance received by local stakeholders in identifying sites for the release of *C. gandolfoi*; this has allowed landowners to co-own the post-release research and be part of the research process. In addition, this improved understanding and acceptance, which has even led to co-funding mechanisms in biological control facilities which would have never previously been thought of. More work is required to raise understanding of stakeholders of concepts such as host-specificity and establishment of founder populations, but the foundations are established for this collaborative learning. One approach might be to develop a biocontrol monitoring programme managed by stakeholders.
- Collaborations between academics and non-governmental organisations (NGOs) have identified and developed ways to ensure that the mass rearing of biological control agents to target *Prosopis* can provide meaningful work for people living with disabilities.[53] In addition, engagement has led to the successful co-funding between various public and private institutions to erect needed facilities. Sustained funding is required to support this initiative, which remains a challenge, but through further co-financing by various stakeholders, it could be achieved. This will require maintained regular engagement and collaboration into the future.
- There are several ways in which *Prosopis* biomass can be processed into products, including biochar and biomass-insulated concrete construction. This would benefit many stakeholders through covering control costs, establishing new industries and promoting job creation. Working together various stakeholders need to collaborate to build the market for these products.

Overall, we suggest that moving forward, research on controlling plants like *Prosopis* should be less about 'studying what the farmer and other stakeholders want' but about how the 'researcher becomes more part of the farmer's/stakeholders' reality' and developing a sustainable partnership between all the stakeholders with a joint mission. We illustrate in this study that this is possible and believe this should become a common practice to reduce research implementation gaps into the future.

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Data availability

The data supporting the results of this study have not been made available by the authors in any format.

Declarations

We have no competing interests to declare. MS Word – review tools (https://www.microsoft.com), Google Scholar (https://scholar.google.com),

ChatGPT (https://chat.openai.com), Crossref (https://search.crossref.org) and MS Power Point (https://www.microsoft.com) were tools used to check summaries and improve language, collate and compile references in journal format, identify links with SDGs, and prepare diagrams.

Authors' contributions

P.I.: Conceptualisation, data collection, writing – the initial draft, writing – revisions, project leadership, funding acquisition. G.v.S.: Conceptualisation, data collection, writing – the initial draft, project leadership, funding acquisition. G.H.: Writing – the initial draft, project leadership. D.O.: Data collection, writing – the initial draft. E.H.: Writing – the initial draft, funding acquisition. P.v.S.: Data collection, writing – the initial draft. E.A.: Writing – the initial draft, funding acquisition. K.W.: Conceptualisation, funding acquisition. M.H.: Conceptualisation, project leadership, student supervision. R.S.: Conceptualisation, writing – the initial draft, writing – revisions. All authors read and approved the final manuscript.

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Evaluating innovation in transdisciplinary sustainability education: TRANSECTS' international learning labs

Evaluative research can advance sustainability education through the learning it can enable, at micro and systems levels. This proposition is explored by examining evaluation practice in a 6-year international programme entitled Transdisciplinary Education Collaboration for Transformations in Sustainability involving universities and biosphere reserves/regions in Germany, South Africa and Canada. A Transdisciplinary International Learning Lab (TILL) was evaluated using a theory-based evaluation approach and interviews, focus groups and questionnaires that yielded qualitative data. Through meta-reflection, we concluded that our TILL had elements of a Field School, rather than a Learning Lab, and that our curriculum required more explicit deliberation among programme developers and implementers towards a deeper and shared understanding of pedagogical assumptions and more congruent practice of transdisciplinary and transformative sustainability education. The reflective, theory-based approach enabled learning from evaluation and was captured in a shared refinement of the theory of change, which makes it explicit that learning from pedagogical innovations is not only for students but also for academics. The paper is an invitation to other innovators in sustainability science, education and evaluation in higher education, to share related findings.

Significance:

Through evaluative research, educators gained insight into how transformative sustainability education and transdisciplinarity play out in practice, and how theory-based evaluation can inform more transformative programme design. As higher education practitioners collaborating across continents and disciplines for systemic change, we noted that transformative concepts do not immediately translate into transformative practices, unless we critically and collectively reflect on practice and outcomes. Such (meta) reflection requires data and purposefully designed evaluation frameworks-in-use. This idea is not new, but its manifestation in practice was illuminative and could also be of scholarly interest to other curriculum and evaluation designers.

Introduction

TRANSECTS[1,2] is a multi-year, international programme, entitled Transdisciplinary Education Collaboration for Transformations in Sustainability, at the intersection between universities and UNESCO biosphere reserves. In sustainability education, there is a quest for innovative curricula that engage participants in learning not only how to analyse complex sustainability challenges but also to work with others to seek solutions.[3,4] It is for this reason that TRANSECTS offers Transdisciplinary International Learning Laboratories (TILLs) on three continents, involving students, mentors and practitioners from diverse disciplinary backgrounds.

The TRANSECTS TILLs are held in biosphere reserves (regions in Canada; hereafter BRs), these being characterised by UNESCO as 'sites of excellence' for sustainability[5], as governance, practice and learning spaces in complex social-ecological landscapes.

TRANSECTS invites graduate students to join BR managers in exploring issues experienced in these landscapes, and consider solutions, with the aim of developing transdisciplinary competencies for sustainability practices.

The TILLs themselves, though interesting as curriculum innovation in sustainability education, are not the main focus of this paper; rather, we reflect here on the use of the framework that the authors co-designed to *evaluate* the TRANSECTS programme[6], including the TILLs. Analysing the use of the evaluation framework to deepen innovative practices is interesting – and a research paper rather than simply an account of practice – because of the manner in which theoretical concepts of sustainability science, transformative higher education[7,8] and transdisciplinarity[9] (TD) are encoded in the evaluation framework.

Furthermore, these concepts have, in the first two years of implementation, been informed and deepened by the application of the evaluation framework.

Context and literature

The need for pedagogical innovation in higher education

The need for higher education innovation in response to sustainability challenges is explored more fully elsewhere[3,4,7,8], but one consideration is pertinent here: that universities' responses to sustainability challenges must include pedagogical innovation[3]. The need for reorienting pedagogical practices is repeatedly emphasised in the quest for impactful learning outcomes for both individuals and society.[7] If higher education is to catalyse and enable *new* ways of thinking, valuing and doing (i.e. to be transformative), it needs to provide learners

with opportunities to critically reflect on existing frames of reference and beliefs and transform them into new ways of understanding and problem-solving, inter alia through a reframing of issues.[10,11] Education becomes transformative when it seeks – contrary to more instrumental approaches – to encourage participants to critique status-quo values and norms and to empower them to become change agents in complex systems[10,11], applying sustainability principles and ethics to address unsustainable practices[7].

Responding to sustainability concerns requires multiple actors to collaborate.[3] In complex sustainability contexts, the role-players are many and have diverse professional and cultural backgrounds, holding often conflicting interests. Educators have thus been proposing concepts like agency[12], action competence[13], interpersonal and sustainability competencies[14], intercultural competencies[14,15], technical and transformational leadership skills[16], relational and transformational[3] competence and reflexive competence[17]. Various curriculum and pedagogical innovations that encourage 'active learning'[18] have been proposed, including project-based learning[19], multi-step social learning processes[20], more generally creating transformative interdisciplinary and intercultural learning environments[21], and the Learning Lab, the pedagogical innovation of choice for TRANSECTS. A Learning Lab (similar to Challenge Lab or Living Lab) is an educational opportunity created for students to engage with a sustainability challenge outside the academy, which is usually multi-faceted, requiring analysis from different disciplinary and non-disciplinary perspectives.[22] In the Learning Lab, the problem is probed through research and stakeholder engagement, and solutions are developed and/or explored, and even tried out to start a further cycle of reflection and development.[22]

The TRANSECTS programme

TRANSECTS was initiated by collaborating universities in Canada, South Africa and Germany, with the lead partner and main funder in Canada. Implementation activities commenced in 2022. These include, among others, new short courses, TILLs and Programme Institutes. In the latter, partners (academics, practitioners and students, from universities, BRs and elsewhere) come together to network, share, reflect, learn and plan.

The team conceptualising TRANSECTS (which includes the authors) produced an evaluation framework to track, reflect and report on all programme processes, outcomes and impacts over its envisaged 6-year lifespan.[6] As TRANSECTS is about exploring innovation and transformations in sustainability education, we aimed to design an evaluation framework that aligned with the transformative intent of the programme and to optimise ongoing learning, as explained below.

Evaluation approaches

When resources are invested in a programme of interventions, evaluation is essential – not just at the end, to satisfy funders, but also along the way, to respond to emerging issues, to improve the programme and its chances of achieving desirable outcomes.

Furthermore, as we show in this paper, evaluation can support reflective practice and *learning*, among programme participants and potentially across a field as a whole.[23]

Evaluation theory has evolved in tandem with broader research paradigm debates.[23] Over time, there have been various responses to the observation that social change is complex, non-linear and seldom easy to capture with pre-test, post-test measurements.[24] Much has been written about the limitations and negative consequences of imposing an 'experimental versus control group' evaluation design onto non-linear social interventions in complex systems.[24-26] Alternative approaches have been proposed to evaluate programme processes and development[24,26], values and narratives[27], principles[28] or identifying the underlying mechanisms that give rise to change[23].

Associated with the latter approach is theory-based evaluation.[29] An early proponent was Weiss[30], who proposed that in order to evaluate a programme of interventions, it is necessary for programme designers to articulate their programme theory, thus surfacing their assumptions of how change is likely to come about (theory of change (ToC)) and their theory of action, explaining why the intervention actions might effect that change. The goal is to evaluate the programme according to this explicit theory, in such a way that the evaluation findings indicate not only *whether* a desired change has taken place but also *why* this change happened, or not.[23] Such insights furthermore create an opportunity to interrogate the programme theory itself, and inform potential scaling.[23]

All programmatic interventions are typically based on a theory of some kind, and most evaluations proceed from a ToC. These theories are, however, seldom explicit.[23,25,30] For example, the commonly used 'logical framework' embodies a programme theory or logic: If *these* activities are undertaken with *these* inputs, then *these* outcomes will eventually lead to *this* desired impact. *How* X is going to lead to Y is seldom explained.

Thus, the recommendations[24,26,30] are to start an evaluation with the articulation of an explicit ToC from which indicators are derived to guide what data should be collected and how it should be analysed. This 'theory' should be open to review, with evaluation creating a feedback loop from which programme designers and implementers can not only make implementation adjustments but also re-think their ToC. Where necessary, implementers can revise the ToC and associated indicators, accordingly.[25,29]

Evaluation framework and tools for TRANSECTS

For the grant application[31], TRANSECTS' programme designers produced a standard tabular log-frame about the relationship between programme inputs, outcomes and impacts (Figure 1). In addition, we produced a non-linear graphic version (Figure 2) that mapped the three change domains that were of interest to us: how *institutions* support transdisciplinarity, *participants' learning* and engagement *practices* in the BR landscapes.

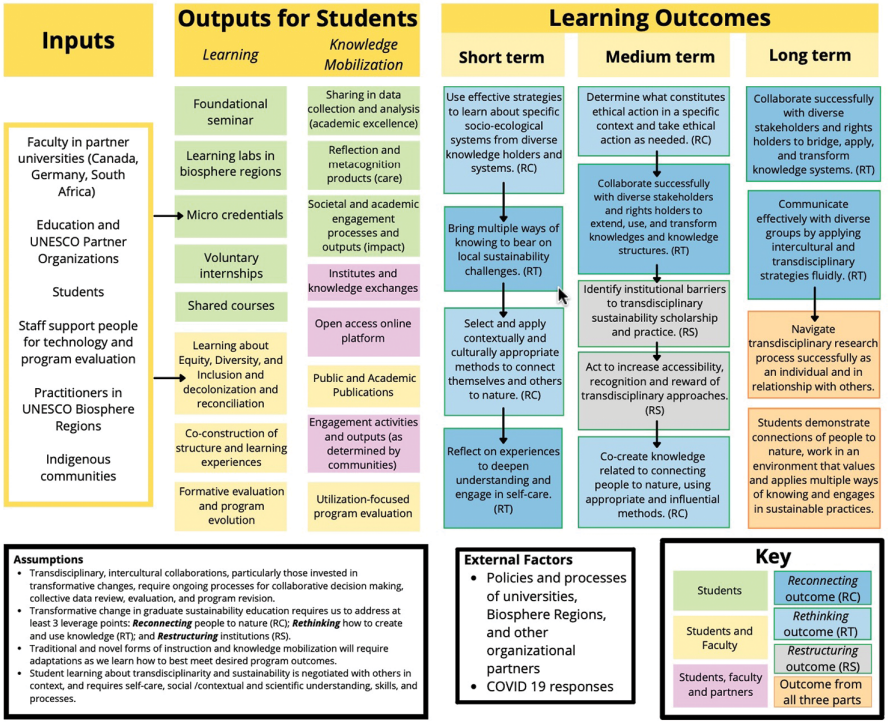
Contrary to the logic presented in Figure 1, we did not assume that change will only take place in a predictable and linear way; therefore, Figure 2 has three concentric circles, with higher education innovations in the centre. While not linear, the general direction of change was nonetheless implied as starting from the academy, rippling out through to the learners, and then to the field of research and engagement practices in BRs, represented by the broadest sphere on the outside of the graphic. Unlike in Figure 1, Figure 2 is explicit that 'learners' include students as well as practitioners and academics.

A cross-section of TRANSECTS partners, academics and practitioners provided support for the ToC representation. Implementers also agreed that from time to time, it should be reviewed and the selected evaluation indicators, instruments and processes adjusted if necessary. This is standard practice, at least according to theoretical descriptions of theory-based evaluations.[26] An evaluation process based on an explicit, non-linear and evolving ToC is, however, a departure from the norm in programme evaluation.[26] The MEL team thus undertook to monitor the evaluation framework itself, as it unfolded, using the ToC to guide data collection, and periodic meta-reflections on emerging findings.

Methodology on which this study is based

The research methodology for this paper is underpinned by the mentioned theory-based evaluation approaches[25,29,30], drawing primarily on qualitative data. Referring to the ToC diagram (Figure 2), planned programme activities were aligned with the three domains of change, and associated evaluation questions created, along with instruments to gather data about those activities. The broad evaluation questions were:

1. Were activities executed as planned and according to TRANSECTS' principles? How, or why not?
2. Were desired learning outcomes, derived from literature in the sustainability sciences and education[3,10] achieved? How, or why not?
3. What other outcomes emerged, relevant to TRANSECTS' transformative intent?



Source: USASK[31]

Figure 1: The logical framework for the TRANSECTS programme.

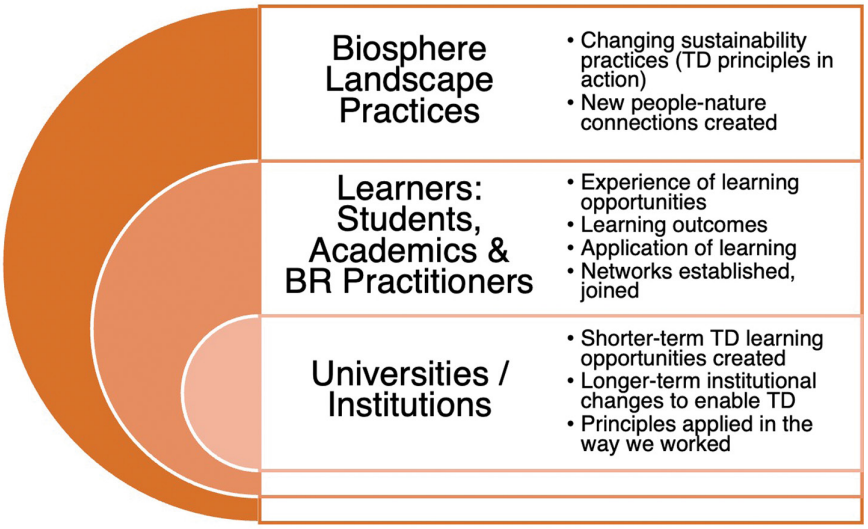


Figure 2: The 2022 graphic of TRANSECTS' theory of change (TD = transdisciplinarity).

The first two TILLs were offered in Germany, starting with a 2-week pilot in 2022. Both TILLs were evaluated, but the 6-week 2023 TILL was evaluated more comprehensively, by both internal and external evaluators. Hence, in this paper, we focus on results from the 2023 TILL.

The evaluation processes consisted of questionnaires, focus groups and individual interviews, which were conducted either in person or online, recorded and transcribed. Both internal and external evaluators gathered extensive confidential qualitative data on the experiences and insights from the various TILL participant groups. Ethical approval was provided by the University of Saskatchewan.

In addition to on-site data collection in Germany, some students who participated in either of the TILLs shared feedback with mentors and programme staff during a Programme Institute in South Africa. This meeting was held some months after the 2023 TILL. Members of the programme design team who were present then engaged in informal meta-reflections on this feedback and other data that had been collected and analysed. During reflections, we applied inter-subjectivity as a means to bring objectivity to our process[32], that is, we challenged each other's interpretations, and when found to be sound, built on them. This included a subsequent online discussion of findings with TILL hosts. The full set of findings as well as methods and instruments are detailed in the primary evaluation report, which is available upon request.[33]

In Tables 1–3, we share *only selected findings* followed by meta-reflections. While all three evaluation questions apply to this paper, the main focus for this paper is question 3: What other outcomes emerged and seemed relevant to TRANSECTS' transformational intent?

Findings

Overview of the 2023 TILL

The 2023 TILL took place in mid-winter in a BR in a rural region of Germany. Its focus was on different forest ownership types, with different management objectives (optimum forestry yield vs. biodiversity, for example). The 17 participating students were graduates, most with master's degrees, representing eight nationalities, and a range of universities, disciplinary and cultural backgrounds. They were selected on the basis of their academic and leadership abilities and their motivation to learn more about transdisciplinary sustainability practices. They stayed in shared accommodation and, for part of the TILL, had to plan and shop for shared meals. The hosts arranged outdoor excursions and meetings where forest scientists shared their expertise.

Configuring the TILL involved many more role-players than the BR hosts. Six weeks before the in situ TILL, students attended a Foundational Course, a series of online orientation sessions and seminars. These included academic presentations on transdisciplinarity, and on Constellation Analysis[34], a transdisciplinary method for analysing sustainability challenges and identifying entry points towards solutions. Besides local instructors, four international mentors were appointed for the first 2 weeks of the TILL, each with four or five students.

Despite concerted efforts to involve them, some mentors were not able to attend all the orientation sessions, and the BR managers found it particularly difficult to attend, possibly due to connectivity and work load. Another key development was that COVID struck during the first week of the TILL, leading to two mentors leaving the site of the Learning Lab early and offering to continue to mentor online; some other mentors and students experienced this as a notable gap in support.

Selected evaluation data

Table 1: Students' experiences and views

When asked, during and after the TILL, to reflect on their experiences, students noted (among other, some very positive, observations) as follows:
The actual problem with research was not clear at the start
How to contribute from their particular disciplines was also not clear, particularly at the start of the TILL
Relationship with BR was not clear; were the students meant to be consultants or even free researchers for the BR?
Living together and working with others' differences was hard for some
A deeper understanding of transdisciplinarity did develop
Students learned much
Students will highly recommend a TILL to others, but with some changes, e.g. stronger transdisciplinary dimensions and learning mediation

Table 2: Mentors' experiences and views

When interviewed, 2–4 weeks after the completion of the TILL, and asked to reflect on their experiences, mentors noted (among other observations) the following:
The use of transdisciplinary methods during the TILL was not explicit
Mentors were not always clear on the problem to be researched, or on who should determine the question – students, mentors or BR managers
The role of the BR managers was not always clear
The scope of the mentoring was not always clear; to what extent should they steer students, and which aspects of the TILL should they facilitate or support?
Dealing with interpersonal conflicts was stressful for some mentors who felt unprepared for it
Mentors would recommend more TILLs (and want to be involved in them) with some changes including more explicit structure and purpose.

Table 3: Biosphere reserve (BR) practitioners' experiences and views

When interviewed 2–4 weeks after the TILL, to reflect on their experiences, BR practitioners noted (among other observations) as follows:
The start of the TILL was too unfocused
Some students had surprisingly little interest in forest ecology
The BR's roles, viz. those of the mentors were unclear
Students were well equipped with technical knowledge to complete set tasks
More conceptual guidance was needed on conservation and governance aspects
The quality of the student assignments presented at the end of the TILL was good.

Programme developers' meta-reflections at the Programme Institute

During the 2023 Programme Institute in South Africa, the authors considered the above data. We concluded that the TILL was a highly rated and worthwhile learning experience for students. However, it did not provide as innovative a *transdisciplinary* learning experience as we had intended. As a collective, we may have conceptualised and approached the TILL more as a Field School, than as a Learning Lab. In sharing with each other what we understood to be the differences between these two curriculum offerings, we found this conclusion to be a sound and powerful explanation for what transpired, that resonated with all of us, and with TILL mentors, when we later engaged them.

In the discussion below, we reflect on why this conclusion is warranted and pertinent for transdisciplinary and transformative approaches to sustainability education – in relation to TRANSECTS (micro-level) but also to wider theory and system building. We also explain the relationship between the evaluation processes and our learning.

Discussion and conclusions: Reflection and elaboration

Our meta-reflection revealed that transdisciplinary curriculum development for transdisciplinary Learning Labs across different contexts is:

- more complex than we had anticipated, particularly in relation to intercultural and relational competencies;
- requires concerted communication between curriculum developers and between developers and implementers (such as Learning Lab hosts and mentors); and
- requires shared and ongoing clarification of transdisciplinary and pedagogical approaches.

What is a Field School, and what is a Learning Lab? What are the differences between them, and why did we think that we have in some ways approached the TILL more as one, rather than the intended other?

Drawing on the literature on Learning Labs and Challenge Labs[22,35,36] and our experience as higher education practitioners in the Geographical and Sustainability Sciences, Higher Education Scholarship of Teaching and Learning, and Environmental Education, of Field Schools (the term used in Canada) or field trips (the term used in South Africa), we identified key differences related to purpose, process and end-points (Figure 3).

We realised that the *purpose* of a Learning Lab, to collaboratively work towards a solution for a problem that has also been jointly identified and explored, and share that solution with each other and possibly a broader range of community partners, should have been made clearer to BR hosts, mentors and students. Throughout the TILL, learning should have been mediated with references back to the Foundational Course and the theoretical discussions on transdisciplinarity. The gap left by the early departure of two mentors signalled just how important learning support was, not only during the first 2 weeks, but throughout – something that was not fully anticipated when the Learning Labs were conceptualised.

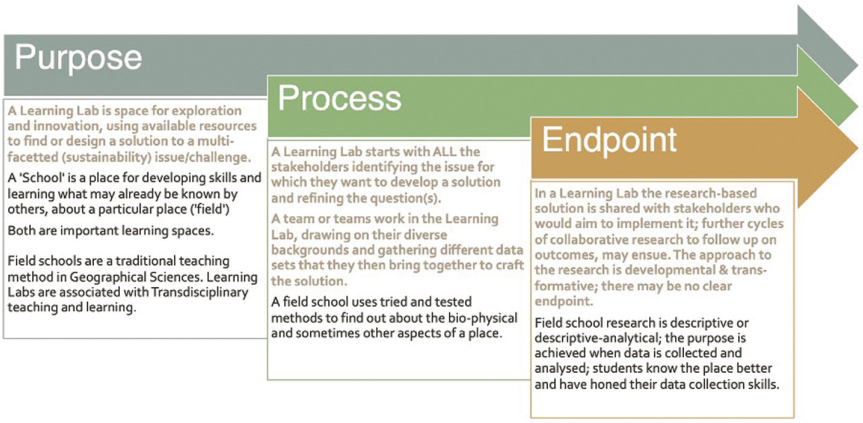


Figure 3: Differences between field schools and learning labs.

Similarly, the value of the diversity of the contributions of students with backgrounds in Politics, Economics, Education, Governance, Forestry, Agricultural Sciences and Ecology, should have been more apparent to all. Students were not attending to simply collect field data as free research assistants. The relevance of inputs from a top ecologist in relation to the sustainability issue under investigation, should have been discussed before and during the TILL, and not assumed.

Learning Labs (and a transdisciplinary process like Constellation Analysis[34]) start with the identification or elaboration of a sustainability issue through community partner engagement because the process of formulating the central problem and associated research question(s) *with* community partners (in this case, BR practitioners, other forestry owners and neighbours) is paramount and not simply a precursor to the research. Thus, Learning Labs require ample time and opportunity for community partner engagement.

Learning Lab participants should agree that the key question(s) to research might not be clear at the start, or at least somewhat fluid; however, there should also be an agreed-upon process for concluding what would be the most relevant question to research. This is a fundamental aspect of transdisciplinary work – not just a preliminary step to quickly get out of the way, or to be handed down before the start of the Learning Lab. In the 2023 TILL students, mentors and BR practitioners were either unclear as to what the key research question was, or unclear about how it and when was to be derived, and by whom.

In some ways, we approached the TILL like a Field School where the focus is usually on collecting bio-physical data, for example, by not fully anticipating the requirements for engagement with community partners. An example is that the majority of BR community partners spoke only German, which only a few students could speak, leaving the majority of students unable to directly engage with community partners.

We also realised that students needed to hear explicitly that challenges experienced around living together (e.g. deciding between meat or vegetarian meals) were part of the intended learning outcomes. Relational[3] or interpersonal[14] competencies are prerequisites for solving sustainability challenges with others[20]. TRANSECTS proposed to develop such competencies by selecting graduate students from different nationalities, disciplinary and cultural backgrounds to participate in the TILLs. We did not anticipate just how steep this learning curve would be for some TILL participants who needed *ongoing and expert facilitated learning mediation* in this regard.

Mentors were uncertain about whether or how to address the challenges that emerged. On a field trip, social conflict and taking time to resolve it is simply a by-product of the primary focus on co-habitating in a remote area in order to (learn how to) collect separate pieces of bio-physical information. In the case of a Learning Lab, however, 'finding' each other (across disciplinary and cultural boundaries) is a key success factor for working together to address a complex problem. Resolving the problem requires participants not only to communicate and work together but also to appreciate and use diverse contributions. Mentors felt ill-prepared to facilitate conflict resolution; it did not feature in the 'job description' and requires skills they either felt they lacked or were not primed to draw on. While mentors and students alike reported that students eventually found peace and even joy in their differences, we collectively missed the opportunity to make the importance of relational competencies[3] explicit and to provide scaffolding to strengthen learning.

In a Field School, mentors have particular roles: providing instruction about data collection, assisting with technical aspects, perhaps socialising after-hours with students to help induct them in the field and assessment of tasks completed. Roles were less clear in this Learning Lab. What were mentors' role in relation to the sett(l)ing of the research question, engaging partners and addressing interpersonal conflicts? The evaluation suggests that there was a need for more explicit learning mediation along the way – that the TILL could not be left to unfold without regular feedback to the students, with reference to the intended learning outcomes, and a recommended suite of transdisciplinary engagement methods from which to choose.

At this point, it should be noted that *the TILL supported key learning outcomes and had many positive features and outcomes for students, mentors and community partners*. For example, the students' final assignments were of good quality and well received by academics and BR practitioners alike; several students asked to attend the next TILLs as mentors; mentors offered to participate in future TILLs; and new relationships between BRs and universities were forged as a result of the shared endeavour. Given such successes, it would in fact have been easy for us to overlook the fact that the curriculum offering was *in some ways* simply a more ambitious version of what we would have offered in the past (a Field School) rather than the fundamentally different intervention (a transdisciplinary Learning Lab) we had theorised it to be.

Why, despite significant efforts by all parties, did we conclude that the curriculum design was not as innovative or transformative as we had sought? On reflection, we realised that our approach to the TILL was predominantly resource-based (asking what resources we have and how best to use them) with less attention to designing curriculum to achieve learning outcomes. We also noted that while students and mentors *had* been briefed about the ways in which the TILL was to be transdisciplinary, this phrase had different meanings and applications. We did not clarify what forms of transdisciplinarity we were seeking to promote. Ironically, we did not consider just what it requires for us as the institutional partners to collaborate as a multidisciplinary team spread across three continents. Online meetings were not ideal for developing a shared conceptualisation of the TILL. Even team members who regularly interact with each other and had, on the surface, shared understandings of the nature of the innovation, also approached it quite differently. Disciplinary differences might have had a role in this, and *thus, it is an instructive example of the situations that transdisciplinary practitioners (including our graduates) find themselves in, in the complex social-ecological landscapes of practice*. We can only conclude, retroductively[32], that

transcending years of excellent disciplinary training were not going to happen in a single event – unless one applies these ideas in practice, and reflects on them, as we attempt to do here, on an ongoing basis.

In response to the evaluation findings, the TRANSECTS programme designers subsequently took several steps to strengthen the planning of future TILLs, including 'backwards' curriculum planning (from desired outcomes to required practices), adjustments to the timing and content of the Foundational Course and increased mentoring support. Changes included more emphasis on communication and inter-cultural competencies, assigning and clarifying pedagogical roles for TILL mentors and hosts, carefully considering the ways in which the proposed TILL focus and research question(s) lend themselves to transdisciplinary and engaged research and innovation.

The findings also informed an adjustment to TRANSECTS' ToC (Figure 4). As noted earlier, theory-based evaluations[23,25,29,30] start with surfacing a shared programme theory from which to derive indicators that guide what data should be collected and what should be evaluated[25]. This ToC must be open to review, and evaluative practices should create a feedback loop from which implementers not only refine implementation but also, where necessary, re-think their ToC and revise it, and the associated indicators. In this case, we have added *evaluation of the process of TILL development* to our MEL framework in order to track the extent to which we are designing for transdisciplinarity. Additionally, we added recursive arrows to make it explicit that change does not only take place among learners in the second domain of change; change also has to take place in the central domain *where higher education institutions need to change the way in which we conceptualise, design and deliver our curriculum offerings*, based on reflective practice informed by feedback from the field. We reiterated that, contrary to the original logical framework (Figure 1), the network of learners consists not only of students but also BR practitioners and academics. We had initially indicated this when conceptualising TRANSECTS (Figure 2) but are now clearer on how this learning can happen. This feedback loop and learning would not have been possible, without evaluation, specifically by applying the theory-based evaluation process we followed.

The use of a non-linear ToC[25,29] encouraged us to be reflective practitioners who *look across the data* of practitioners, mentors and graduate students, given that our ToC presents the relationships among these domains as important, if as yet under-theorised. The ToC afforded deeper thinking than if we had simply counted numbers of participants, or checked whether learning outcomes had been achieved. A simple, but significant, flow of the key elements for students, practitioners and mentors made it easier to engage in deep conversations around what the evidence indicated, without the limitation of a narrower focus on specific outputs or structures of a standard logic model.

The results of evaluation-in-use include deeper iterations of the programme theory, notably the distinctions between a more standard Field School and what a transdisciplinary and intercultural Learning Lab was intended to do. Working reflexively with a ToC proved even more significant given the number of people involved in the evaluation, and communicating across continents, time zones and disciplines, and complex TILL experiences.

Ultimately, some of the best evidence of strong evaluation is the capacity to use it in situ[25] to make changes iteratively. Thus, we confirm the value of theory-based evaluation and working iteratively with a programme theory. As Oberlack et al.[37] argued:

> *ToCs trigger debate among the stakeholders and evaluators of an initiative regarding the hypothesized and observed effects of actions as well as regarding underlying assumptions about how change happens. Therefore, they can strengthen the effectiveness of research, practice, and education in sustainability science.*

Our study shows that a ToC approach to evaluation can catalyse not only a more rigorous evaluation focused on the change process, but it can also frame and catalyse the kinds of relational and deliberative processes needed to collaboratively make sense of evaluation data and insights, to make improvements to an ongoing programme, and perhaps also to contribute to theory development in an emerging field.

Coda – The role of evaluation in developing transformative higher education curricula

When one of us shared some of these findings at a conference that invited delegates to explore 'bridging theory and practice', the moderator congratulated TRANSECTS on being prepared to share and learn from our 'mistake'. The term 'mistake' was surprising and served as a reminder that reflective practices – learning from reflecting on doing – are not common practice in higher education. The drive for sustainability transformations should surely be characterised by experimentation where the term 'mistake' might not be the best way to describe an exploration of innovation attempts that require refinement; sustainability challenges necessitate critically evaluative ways of working. The paper provides one example of an evaluation framework and process that yielded both data

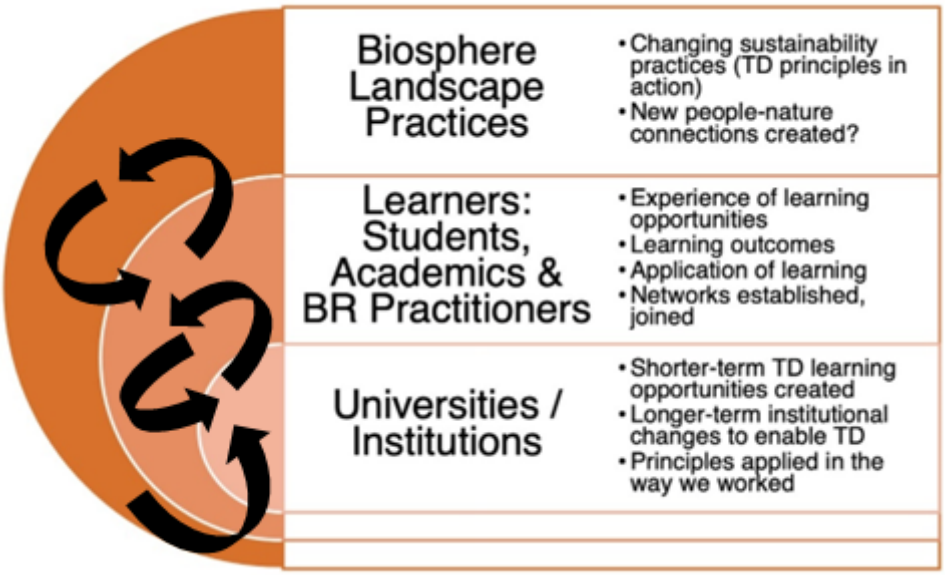


Figure 4: TRANSECTS' more explicit theory of change graphic with recursive arrows (TD = transdisciplinarity).

and insights, and thus also the evidence that evaluation, if approached as a form of theory-driven and data-informed feedback, can assist higher education practitioners to deepen insights into practice.

The paper illuminates how concepts of transformative sustainability education play out in practice, how challenging it is to develop a common strategy for transdisciplinary work and how evaluation can inform more transformative programme design, implementation and learning for *all* participants. As higher education practitioners collaborating across continents and disciplines for transformations in sustainability education and practice, we learned that transformative concepts do not automatically turn into transformative practices and require collective and critical reflection-in-practice. Such (meta) reflection requires congruent evaluation frameworks-in-use. While this idea is not new, its manifestation in practice was illuminative, and we have already seen that other curriculum and evaluation designers also find it insightful.

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Data availability

The data supporting the results of this study are available upon request to the corresponding author, provided our research ethics protocols are adhered to.

Declarations

We have no competing interests to declare. We did not make use of artificial intelligence for data collection, analysis or writing. Ethical approval was provided by the University of Saskatchewan (Application ID: 3808).

Authors' contributions

E.R.: Conceptualisation, methodology, research tools, data collection, analysis, writing – the initial draft, writing – revisions. J.C.: Conceptualisation, methodology, research tools, data collection, analysis, data curation, validation, writing – revisions. M.R.: Analysis, validation, writing – revisions, project leadership, funding acquisition, acquiring ethics clearance certificate. W.J.: Conceptualisation, methodology, research tools, data collection, analysis, data curation, validation, writing – revisions. J.G.: Data collection, analysis, validation, project management, funding acquisition. H.W.: Conceptualisation, data collection, validation, writing – revisions. All authors read and approved the final manuscript.

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Engaged sustainability science and place-based transgressive learning in higher education

This article is located within current debates on engaged science and learning in higher education, with emphasis on types of learning emerging from engaged sustainability science, and associated contributions to debates on decoloniality in higher education. In particular, the article deliberates how a focus on sustainability science practised as place-based transgressive learning can add to debates on decoloniality in higher education. Through analysis of two case studies, we propose that co-engaged place-based research and learning emerges as a form of multi-loop, transgressive learning that offers possibilities for advancing understanding of decolonising learning processes, at least in those parts of the higher education system where the learning and sustainability sciences meet. This is offered as an approach to deepen science engagement in contemporary African contexts.

Significance:

- The article offers insight into how science engagement practised as place-based, transgressive learning can contribute to decolonisation of higher education, especially through learning processes.
- It draws on insight from the learning sciences (notably Bateson's work on single, double and triple loop learning, but also theory from decolonial, expansive and transgressive learning) and shows how this can deepen understandings of science engagement practised as place-based transgressive learning.

Introduction

In the South African Department of Science and Innovation Decadal Plan (2022–2023)[1], there is a strong commitment to science engagement. However, most references tend to refer to processes of communicating science. There is recognition that science engagement should contribute to scientifically literate societies and that this can enhance inclusivity in science programmes. However, there is no explicit reference to the relationship between science engagement and ***learning,*** *or how such inclusivity processes come about*, and there is also no reference to how this should contribute to wider processes of curriculum transformation in higher education. The Decadal Plan[1(p.9)] tends to relate such processes to the need for more inter- and transdisciplinary science, noting that, "A critical defining characteristic of transdisciplinary research is the inclusion of stakeholders in defining needs and hence research objectives and strategies". However, again, there is no clear link between transdisciplinary research, stakeholders' involvement and ***learning,*** or what this means for transforming higher education learning processes. It is this gap that this paper addresses.

Theorising engaged science and learning in higher education with decoloniality, place and transformative, transgressive learning

The efforts towards inclusivity in science practice heralded by concepts of science engagement, and engaged transdisciplinary sciences, can be read more broadly in relation to post-colonial debates about decolonising learning processes, curriculum and higher education research processes. In this paper, we focus mainly on learning processes, with an understanding that these are related to curriculum and research in engaged sustainability science activities. To date, much learning in higher education has been oriented towards individual achievement and progression. This, in our view, raises the need for further inquiry into the *types of learning* that may be more inclusive and thus potentially also transformative (meaning they lead to perspectival shift)[2] or transgressive (meaning they challenge unsustainable norms, forms of oppression and systemic dysfunction)[3,4].

Internationally, the calls for decolonising higher education research, teaching and learning processes are not new, with Ngũgĩ wa Thiong'o's[5] seminal call for 'Decolonising the mind', and Fanon's[6–8] multiple works challenging the paradox of embodied forms of coloniality, including in education, where his call is for a form of 'lived learning'.[9] Authors such as Ndlovu-Gatsheni[10], and Mbembe[11] produce interesting multi-layered analyses of the demands for epistemic decolonisation in higher education which, in short, involves ***unlearning*** coloniality. The question is how should such 'unlearning' progress? Various authors offer suggestions; for example, Bozalek and Zembleyas[12] suggest a need to unlearn the coloniality of affects, while others propose unlearning the discipline[13], unlearning certain expected knowledge sets which calls forth insurgent acts and radical anti-racist imagination[14], while Mbembe[10] argues that forms of reasoning need to change, as he relates the notion of 'unlearning' to the realities of climate change in Africa. Rodríguez Castro[15(p.59)] argues for a "socio-historic, geographic and place-based approach to learning, in which she addresses her positionality through "critical feminist reflexivity, and decolonial and anti-racism work". In his second thoughts on decoloniality, Mignolo[16] argues that the unlearning of coloniality reaches beyond epistemic transformation and should include serious engagement with land and place, which brings us to a focus on place-based sustainability science engagement and learning in higher education.

Place-based research and learning in higher education has been described by Woodhouse and Knapp[17] as originating from the attributes of a place, being inherently multidisciplinary, being inherently experiential, reflecting an educational philosophy which transcends 'learning to earn' and connects place with the self and community. Place-based research and learning, as used in this paper, is premised on a particular understanding of place. Three broad conceptions of place help to differentiate. The first understanding of place dates back to the 1950s and has its origin in the discipline of Geography, whereby place is understood in technical terms as area and locality – as

coordinates on a map.[18] Such a notion of place suggests an abstract notion of dehistoricised spatiality devoid of inhabitants, be they human or more/other-than human.[19] The second is a phenomenological notion of place, based on the idea that in experience nothing is unplaced[20,21], recognising that we are beings in the world. This is a view of place that is not characterised by universal laws and spatio-temporal space but by distinct neighbourhoods, local events and communities and that recognises that relationships with/to such places elicit feelings, moods, perceptions and attitudes.

Most relevant to this paper, the third broad sense of place concerns a critical, resisting and regenerative notion of place. This notion of place recognises that places have been colonised and, in a neoliberalising world, are characterised by discourses of accountability and economic competitiveness. This view of place also recognises that places can be renewed or regenerated through processes of restoration, maintenance, transformation, care and/or re-membering, which involve the (re) discovery of both self and place.[22] Resisting and regenerating is salient to decolonising places. Mies and Shiva[23] argue that places concern living resistance to colonial constructs of race, gender, nature and value – places mean resisting that which is disembodied, dematerialised and deracialised.

Learning with place in resistant and regenerative ways means transgressively learning and manoeuvring around the "impasses of human agency, the linearity and limitations of capitalist teleology", in the process upturning the dominating "substructures of our experience as a species', recognising that, "the very materiality of the world is inescapably entangled with epistemology and justice (or 'justice-to-come')"[24(p.828)]. Such a view of place embodies "relations of responsibility"[25(p.265)] or response-ability[12] where researchers and learners are embedded in, and part of the tapestry of becoming. In this article, our framing of sustainability science as place-based research and learning is aligned with the third broad notion of place, because it concerns researchers and students learning sustainability together with/in local communities and through culturally attuned, and place-centred democratic processes. Here, sustainability concerns of local communities in place form the primary focus of engagement, and learning is not left to individuals for independent progression, but is rather oriented towards socially situated, place-based reflexivity and change that respect and take account of indigenous people's epistemologies, ways of being and experiences.[26]

With the above discussion on science engagement and (un)learning in mind, we draw on Bateson[27] whose work makes it possible to differentiate between types of learning using a recursive conceptualisation of first, second and triple loop learning[28]. We draw on this because it is also widely used in the sustainability sciences to frame empirical studies on learning.[29,30] ***First loop learning*** (Level I in Bateson) sees learning primarily as science-based information transfer leading to acquisitional outcomes for the individuals concerned, i.e. learning *about and for* sustainability concerns. ***Second loop learning*** (Level II in Bateson) sees learning outcomes as socially critical engagements with causes of environmental problems, with learning being constituted both f*or and as part of* the sustainable development process. ***Triple loop learning*** (Level III in Bateson) sees issues as complex, and learning outcomes as uncertain, constituted by ongoing reflexive processes of social or collective forms of learning 'what is not yet there'[31–33] in and from place, relations and context. Bateson[27(p.302)] talks about this learning as perceiving and acting "in terms of the contexts of contexts", denoting the need for contextual critique, unlearning, reflexivity and the kind of regenerative place-making mentioned above. This type of learning embraces indeterminacy, ontological and epistemological plurality and multi-voicedness, thus offering potential for the type of resistant, regenerative and transgressive learning referred to above.

Methodology

To provide an empirical base for elaboration of our argument, we draw on two case study examples of sustainability science engagement practised as place-based research and learning. A case study is typically "an empirical inquiry that investigates a contemporary phenomena ('the case') in depth and within its real world context"[34(p.16)]. In each case, researchers focused on how the place-based expansive learning was constituted and emerged over time. In both cases, researchers were positioned as co-engaged researchers using co-engaged methods typically used in expansive learning research, which involve developing understanding of the contextual dynamics, challenges and questions with actors in the context, and probing these together to identify and work out alternatives to contradictions, problems and challenges experienced by people in the contexts concerned, typically also leading to transformative agency and changes in the settings.[35,36] Thus, both cases are case studies of expansive, transgressive learning with communities in complex socio-ecological relational configurations (cf. Table 1). In each case, postgraduate scholars working in the sustainability sciences collaborated with lecturers and other students (e.g. diploma or degree students) and a range of community actors (e.g. government officials, non-governmental organisations, farmers associations), to undertake co-engaged research and learning with communities around place-based matters of concern that affect the communities they engage with (e.g. water for food, food insecurity). Expansive, regenerative learning actions emerged over time, with the collaborating participants together uncovering and unlearning taken for granted norms, and reflexively learning 'what is not yet there' in the contexts.[32] Each time the matters of concern and the associated groups were co-defined in place-based contexts.

Case studies of sustainability science and place-based transgressive learning

The first case (led and documented by Lotz-Sisitka et al.[35]), developed over an 8-year period of extensive ongoing co-engagement, emerged in the rural Eastern Cape, South Africa, where postgraduate scholars from two universities and diploma-level students in an Agricultural Training Institute (ATI) have been working with rural farmers on sustainability challenges related to land and water for food production in a post-apartheid land reform setting where indigenous farmers were given back their land. Farmers were being given some support from the local government to develop sustainable agriculture as a means of economic production and livelihood, but they had little or no access to water.[35] The second case (led and documented by Mphepo[36]) emerged in rural Malawi, and developed over a 4-year period, where postgraduate scholars and degree-level students in the local university were working with rural women farmers to increase agricultural production in the face of regular 'drying' of the local lake system.[36] In both cases, small holder farmers were affected by drought conditions, which were reported and recorded as being more severe than earlier times.

While each of these cases documenting processes of sustainability science place-based research and learning are extensive[35,36], in Table 1, we highlight some of the most salient features of the processes followed, outlining the place-based co-engaged learning sequence and ontological and epistemological dynamics involved, including the outcomes of the place-based research and learning processes over time. We also point to the 'unlearning' that was involved in each case. We purposefully draw on cases from two different southern African countries, to broaden our insight into decolonial learning processes informed by experiences on the African continent, not only South Africa.

In Table 1, we summarise key contours of the learning processes in the two cases before discussing them in more depth.

Discussion of the cases

As can be seen from the above cases, there are interesting insights into the sustainability science engagement research and learning processes, which include:

- the importance of diverse perspectives and different forms of knowledge converging through co-engaged interactions over time, and identification of what needed to be 'unlearned',
- the grounded nature of the matters of concern that are place-based and embedded in human–environment relations, local cultures and knowledges,
- relationality is core, involving nature-culture relations as well as critically constituted relations of empathy, care and solidarity, all of which provide motive for learning and which grounded both resistance and regenerativity in place.

Table 1: Cases of science engagement as place-based research and learning processes

Features of the unfolding place-based research and learning process	Case 1: Access to water for food production in rural smallholder farming communities (Eastern Cape, South Africa)[35]	Case 2: Women's empowerment in food production in climate change adaptation programmes (Lake Chilwa, Malawi)[36]
Context of the research and learning processes	Smallholder farmers in the rural Eastern Cape were given back land via land reform in post-apartheid period but had no access to water. There was local economic development support for their practice, but no support for water infrastructure maintenance and supply.	In the Lake Chilwa area in Malawi, communities are dependent on fishery. Levels of poverty are high, and the area is experiencing periodic droughts that lead to 'drying up' of the lake. This has a significant impact on local food security and puts additional pressure on women farmers.
Matter of concern as articulated by communities in place	Farmers were seeking support for addressing their 'water for food' problem. They wanted to know more about rainwater harvesting and conservation (RWH&C) practice relevant to their scale of farming.	Women farmers were experiencing food insecurity stress as a result of the lake drying up. They have valuable indigenous and local knowledge of food production (including the use of Open Pollination Variety (OPV) seeds), but this was being undermined by extension officers who were promoting mono-culture and hybrid seeds.
Sustainability-oriented challenges identified	Drought was reported to be more frequent in the area, affecting already difficult conditions for developing farming enterprises.	Drought affects normal food production rhythms, where conditions of poverty are already severe. Women household food producers are most under stress.
Learning-oriented challenges identified – including what had to be 'unlearned'	Excellent information available on RWH&C practices produced by the scientific community, even available in the local Agricultural Training Institute, but not being used due to historical influence of mono-culture agriculture dominance in the curriculum; the latter needed to be 'unlearned' to make space for more plural accounts of agriculture.	Some knowledge available on climate change adaptation practices. The validity of women's indigenous knowledge, however, was marginalised. Dominance of mono-culture and hybridised seeds being promoted by extension services and scientific organisations, including local scientists and market actors, with both patriarchal dominance over what counts as valid knowledge and agriculture mono-cultures needing to be unlearned.
Summary of the co-engaged research and learning process followed	There was a common interest in advancing knowledge of RWH&C to address the smallholder farmers' problem, among farmers, and local economic development officers, Agricultural Training Institute lecturers and farmers' association. A learning network was formed, supported by a 'navigation tool' that gave access to more detailed information on 26 RWH&C practices (produced by water scientists for the Water Research Commission). The learning process started with mobilising local indigenous knowledge of farmers, which created space for further choices of RWH&C practices and development of collective demonstration sites. The collective demonstration site process expanded over time across the community. Farmers started assisting each other and an indigenous collective farming practice 'illima' was re-instituted in the community, and offered practice-based learning opportunities for Agricultural Training Institute students. Community radio tools and digital tools such as WhatsApp were also used for wider social learning and ongoing knowledge exchange and co-learning.	There was a common interest in finding ways of responding to the implications of the drying lake and its impact on local food security, especially among women farmers and non-governmental organisation partners, and the university research team. A process of working with the women farmers to surface their knowledge and learning was initiated, and a scenario-building approach was used to surface women's desired options for resolving the matters of concern. This combined science and arts-based methods and offered a cultural translation tool to approach the gendered environment. This led to the establishment of comparative demonstration plots where women's indigenous agricultural knowledge was applied and compared to the production resulting from the knowledges being shared by extension services. The university and students assisted with scientific analysis of the resulting production processes and outputs. This helped to both surface and validate the women's knowledge which showed higher levels of production output from a food security point of view. This also addressed some of the gender-based challenges identified.
Features of the ontological and epistemological experiences reported	Motivation to seek out new knowledge was grounded in matters of concern of interest to the communities in place. Indigenous knowledges provided means of evaluating and expanding existing knowledge and experience. Co-defined approaches providing access to new knowledge and co-engaged critically situated experiences (e.g. demonstration plots development) helped with identification of knowledges necessary for advancing practice in co-defined ways. Empathy for older women farmers was catalytic in establishing the learning network and solidarity relations, which were crucial in catalysing regenerative collaborations in place.	Motivation to seek out different approaches to food security as a climate change adaptation strategy was grounded in the matters of concern of the women farmers in place. Indigenous knowledges were surfaced, as well as local gender and modernisation politics that were subjugating women's knowledges. Through arts-based methods, new communication tools were developed, which produced spaces for a wider scope of knowledges to emerge and be tested out in practice. The materiality of the indigenous farming practices was crucial to the resistance and regenerativity in the context. In the process, new relations of solidarity were created.
Observations on place-based transgressive learning	Learning was iteratively grounded in encounters with situated, historical, existing and new knowledges. These were combined iteratively over time with critical analysis of the status quo (why water systems were not in place) and trying out new theory-practice combinations that seemed feasible and meaningful to the socio-material situation. The process was multi-voiced and recursively expansive around the matters of concern over time.	Learning was iteratively grounded in encounters with situated, historical, gendered, existing and new knowledges. These were combined and evaluated through a critical analysis of politics of subjugation, which allowed for surfacing marginalised knowledges of women, and trying out alternative possibilities, and making their validity more visible through experimentation and dialogue. The process was multi-voiced and recursively expansive around the matters of concern over time.

...Table 1 continues on next page

Table 1 continued...

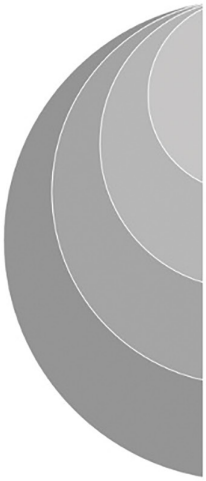
Features of the unfolding place-based research and learning process	Case 1: Access to water for food production in rural smallholder farming communities (Eastern Cape, South Africa)[35]	Case 2: Women's empowerment in food production in climate change adaptation programmes (Lake Chilwa, Malawi)[36]
Documented outcomes of the place-based research and learning processes for farmers, students and other actors	**For farmers:** they were more able to test out and use a wider range of RWH&C practices and were able to gather support and new knowledge resources for their practice; improving food production at local levels and validation of their indigenous knowledge and practices, while also expanding these. Stronger relations of solidarity were also established which they continue to draw on.	**For women farmers:** increased levels of food production; validation of their indigenous knowledges and embodied knowledge and practices; changed gender relations; stronger solidarity networks that validated their status and capabilities as primary food producers building on their socio-material relations with the land and food production processes.
	For students: they were more able to iteratively relate theory and practice, and their modalities of learning were expanded and more substantively grounded in the materiality and social experiences and knowledges of communities, equipping them better for responding to risk and matters of concern.	**For students:** more able to iteratively relate theory and practice; develop insights into the validities of a diversity of forms of knowledge; to ontologically ground their learning; equipping them better for responding to risk and matters of concern.
	Other actors: the solidarity network strengthened relations of empathy and community building and has equipped diverse actors to be more responsive to farmer's needs, a tendency that has shaped curriculum review in the Agricultural Training Institute, and ongoing supportive engagement with farmers over a period of approximately 10 years now.	**Other actors:** a wider repertoire for responding to recurring drought conditions, and abilities to use multi-methods that include aesthetic processes, and complex conversations such as those arising in the gendered environment. Relations of empathy and community building and solidarity networks strengthened, with ongoing networks of supportive co-learning in place.

In both cases, we see resistance and regeneration being co-constructed in place-based contexts in multi-actor formations as no one form of knowledge or experience was seen as adequate in responding to matters of concern. In both cases, a plurality of knowledges and forms of engagement were sought out in collectives, through the situated, place-based engagements with matters of concern that were shared. In both cases, colonially shaped unsustainable practices were identified which had to be 'unlearned' (e.g. dominance of mono-culture agriculture in Case 1, exclusion of rural women's knowledges in modern extension services in Case 2). Solutions were not pre-determined or fixed, and alternatives to what were perceived to be unsustainable norms or oppressive practices were co-constructed through different co-engaged learning and relational change processes (e.g. in Case 1, they used a 'navigation tool', and in Case 2, arts-based scenario methods, and in both Cases 1 and 2, they used demonstrations). In both cases, indigenous knowledge and other forms of knowledge were mobilised concurrently to resolve contradictions and problems being experienced. In both cases, solidarity relations and network building were key to the sustainability science engagement practised as place-based research and learning process.

Mainstream science learning processes, and even recommendations for 'communication approaches' to science engagement in higher education tend mostly to advance forms of first loop learning. With the need for co-engaged transdisciplinary approaches to sustainability science being articulated as a strategy for inclusivity in the sciences[1], and drawing on the learning sciences mentioned above[27,28], one could easily argue that second and third loop learning might better guide decolonial place-based learning and that these ways of describing the unlearning and regenerative learning better reflect the learning in the two cases. This could easily lead to instrumentalising such learning processes in higher education.

However, a more nuanced reading of the literature on first, second and third loop learning warns of instrumentalising reflexive and transformative learning (especially triple loop learning) as a "a form of deeper strategic thinking" that seeks "utopian solutions through ever higher orders of learning"[28(p.303)]. Tosey et al.'s[28] point is that triple loop learning is often erroneously interpreted as an "ever higher" order of learning and that learning at Level III in Bateson's original work[27] (from which most triple loop learning applications are derived, including in the sustainability sciences) is not achievable by 'instrumental means'.[28] Instead, such learning is generative and unpredictable and by definition not controlled, indicating that educators or researchers are not able to engineer the future by turning these processes into pedagogical methods and that such processes should necessarily remain open-ended. Furthermore, Tosey et al.[28] point to the complexity of Bateson's Learning III, noting further that it differs from most adopted conceptualisations of triple-loop learning in that it reveals a dark, difficult side to transformation, is non-instrumental, exists beyond language and is recursive"[28(p.303)]. Reynolds[37] argues that interpretations of triple loop learning may benefit from "being grounded more in understanding, engaging with, and transforming social realities", as in our two cases (cf. Table 1). Essentially, this more careful reading of the learning science literature in the context of sustainability science engagement and learning raises the question of open process, rather than controlled pedagogy.

Interesting too, Bateson does not reduce Learning III to rational deliberation or discussion, but he includes the role of the unconscious and aesthetic, "saying that learning entails a double involvement of primary process and conscious thought"[38], accommodating not only 'hard facts' but references to emotions, aesthetics, spirituality, the sacred and "transconceptual experience"[38(p.61)], for example, the unlearning of colonial 'affects' as argued by Bozalek and Zembleya's[12], or Fanon's 'living learning'[9], as was the case for women in Case 2, and also in Case 1, if less explicitly. Tosey and Mathison[39] propose a development of Bateson's original framework with emphasis on "multiple modes of learning" (i.e. embodied, analytic and aesthetic) identified in Bateson's writing, which we see arising the two cases above where the embodied significance of demonstration sites (the kinds of 'living learning' referred to by Fanon's work[9]) in Cases 1 and 2, and the use of arts-based methods for co-producing alternative views and possibilities in Case 2, led to planting practices with rural women that helped them to challenge patriarchal and oppressive relations, and affirm their indigenous knowledge, leading to significant food system benefits. This leads us to consider what has not yet been considered adequately in the learning sciences, namely, aspects of aesthetics, cosmology and arts in the opening up of possibilities for expanded third loop learning interpretations as articulated by Tosey and Mathison[39] and thus also decoloniality of learning processes.[40] We also note that our cases reflect a recursive relationality between first, second and third loop learning premises, as outlined in Figure 1 (i.e. the processes were not separate but iteratively related), a relation that Bateson[27] also alerts us to in his original work. What is interesting is that Bateson noted that Level III learning is extremely difficult for individuals in constrained psychological



Recursively related learning levels	Case 1 & 2
Learning 0	Starting point of co-engaged interaction ; matter of concern as articulated ; prior knowledge and experience (including IK)
Learning 1	Factual information on water harvesting approaches (C1); and food production sciences (including IK on successful food production methods); changing weather patterns; soil moisture; nutrients etc. (C2)
Learning II	Delving into wider issues such as governance failures; gender inequalities; and histories of poverty and exclusion; dominance of mono-culture cropping in ATIs and extension services (C1&2)
Learning III	Scenario building to probe possibilities through cultural-aesthetic representations that resonated in context, combined with practical experiments drawing on women'' IK and embodied experiences (C2); expanded options through mobilizing new praxis through 'ilima' (cultural-embodied praxis) and further experimentation with RWH&C demonstrations (C1); included transgressing norms and integration of IK knowledges and cosmology; improved eco-cultural relations, and ethics of care, empathy and solidarity advanced

Figure 1: Case interpretations of Bateson's[27] recursive levels of learning.

learning experimental conditions, but our cases, along with other related research, shows that this seems to be less so in place-based transgressive learning collectives.[32,33]

The cases also show the need for explicitly including a focus on transgression in discussions on triple loop learning, especially transgression of unsustainable norms and practices (e.g. transgression of mono-culture agriculture and high-intensity irrigation praxis, dominant narratives of hybrid seeds of extension officers, dominant patriarchal cultures marginalising women's knowledge)[3,4,35,36], as these seem to be where co-learners are collectively able to practice those reflexive processes of perceiving and acting "in terms of the contexts of contexts", which, as noted above, Bateson[27(p.302)] refers to as being a key feature of Learning III, difficult as this is. Our cases show that this can help to overcome the nature–culture bifurcation, fact-value and expert-novice dichotomies that characterise mainstream higher education learning processes, where the emphasis remains mainly on acquisition of disciplinary knowledge. As indicated above, decolonial theory and associated studies articulating what needs to be 'unlearned' emphasises these limitations and argues for a need to broaden ways of knowing and the scope of knowledges and forms of learning encountered in higher education.[40-42]

Importantly to the discussion of our cases, and the emerging argument, is that the dualist logic of Western modernity has seen an artificial separation between indigenous and Western science knowledges.[40,42] As a consequence of European colonialism/imperialism, modern Western science has been given the superior status of 'knowledge', whereas the knowledges of colonised people are regarded as mere 'culture'.[43] The superior status given to Western modern science and its constructed separation from indigenous knowledge has been challenged by decolonial scholars, postcolonialists, feminist philosophers of science, multiculturalists, sociologists of knowledge, and so on.[42] An imperialist view of knowledge privileges representation rather than performance and declares knowledges as different, superior/inferior. However, when the performative side of knowledge is accentuated as in our two cases and via the recursive single-triple loop process (Table 1 and Figure 1), then science and engaged science is understood as a situated activity which connects people, sites, place and forms of knowledge relationally. In other words, science/knowledge is locally co-produced through processes of negotiation based on the social organisation of trust and the co-construction of meaning using diverse approaches to knowledge (e.g. drawing on indigenous knowledge while also conducting comparative science experiments on productivity related to local indigenous knowledge as in Case 2). It is not reliant on empirical verification/falsification as the only means of valorisation. Viewed in this way, seemingly disparate knowledge traditions can work together to produce new knowledge in new knowledge spaces, and/or regeneratively recover the existing validity of marginalised knowledge[42,36], enhancing sustainability science engagement beyond 'communications'.

While the curriculum is not the focus of this paper, if applied to the curriculum and its strong relation to learning, such learning positions the curriculum as an active force[44], meaning that the curriculum is not predetermined but immanent to the present situation of places and an outcome of the intra-actions that occur among humans and in relation with the more than human via the learning process. In other words, the curriculum is always curriculum-to-come. This view of curriculum is aligned with discussions on transgressive, regenerative and triple loop learning deliberated above, as well as decolonial[32] and some forms of posthuman curriculum theorising[45,46]. Curriculum can be conceptualised as 'transgressive moment'[47] if science engagement approaches such as those in Table 1 are developed as open process service learning or other engaged learning programmes in higher education (avoiding instrumentalisation as noted above). In our cases (Table 1), we can see that sustainability science engagement can be a transgressive movement[3,4], constituted as an open process of unlearning, co-learning and becoming in place for researchers, community members and other actors alike, with the potential to inform curriculum transformation and learning theory development in higher education.

Conclusion

In this paper, we have sought to offer a perspective on how place-based learning and research can be conceptualised and enacted as sustainability science engagement in higher education settings. As can be seen from the two cases in Table 1, this requires that academics and students collaboratively co-engage with communities around their matters of concern in place, and in the process involve other actors (including the more-than-human) and a plurality of cultural tools (e.g. diversity of knowledges as well as ethics of care, solidarity and empathy and sensibilities to a plurality of eco-cultural relations). These all work together to support communities and academics and students to unlearn, and learn how to respond to their particular matters of concern through emergent processes that are reflexive in and of context, and which remain open-ended, creating new or regenerative possibilities for being and becoming in practice, in the process breaking away from modernist and colonial dualisms. Confronting structural and/or historical challenges and contradictions and challenges with others can lead to identifying what needs to be unlearned and regeneratively replaced. Allowing for open processes of learning creates space for possibilities to be elaborated via co-engaged attempts to resolve these contradictions and challenges in embodied multi-actor formations where students in universities offer relations of solidarity and care, as well as research-based support, co-learning from the process.

Our argument is that sustainability science engagement, conceptualised and practised as place-based forms of transgressive learning, can extend conceptualisation of science engagement beyond communication to give deeper meaning to inclusivity. Our cases show this can extend decolonial practices in higher education and can also help to answer the 'how' question in how transdisciplinary science practice can unfold, at least in those parts of the higher education system where the learning and sustainability sciences meet.

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Data availability

Data used to construct the two case studies are available from the authors on request.

Declarations

There are no competing interest declarations associated with this research. We did not use AI in the preparation of this manuscript.

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Authors' contributions

H.L.-S.: Conceptualisation (partial); literature review (partial); methodology development for Cases 1 and 2; data collection oversight for Cases 1 and 2; data analysis for Case 2 (partial); data curation; writing – the initial draft (partial); writing – second draft (full); student supervision for researchers in Cases 1 and 2; project leadership of Cases 1 and 2; and funding acquisition for Cases 1 and 2; funding acquisition for writing collaboration. L.L.G.: Conceptualisation (partial), literature review (partial); writing – initial draft (partial); review (second draft). G.M.: Conceptualisation (partial), data collection for Case 2; data analysis for Case 2; validation; data curation (Case 2); writing – the initial draft (partial, mainly Case 2); review (second draft); field-based leadership (Case 2). All authors read and approved the final manuscript.

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Transdisciplinary curriculum design for sustainability transitions: A reflective dialogue

Inter- and transdisciplinary curricula can potentially develop an integrated understanding of an increasingly interconnected, complex world and develop students' agency, empathy, creativity and critical thinking skills. Within the South African qualification landscape, the Postgraduate Diploma (PGDip) is identified as a multi- or interdisciplinary qualification that allows working professionals 'to undertake advanced reflection and development by means of a systematic survey of current thinking, practice and research methods in an area of specialisation'. In this paper, four academics reflexively share their experiences of (re)developing and piloting transdisciplinary curricula for the PGDip in Sustainable Development (at Stellenbosch University) and the PGDip in Sustainability Learning (at Rhodes University). Reflections centre around the rationale, context and emergence of the two programmes, their structure and intended learning outcomes, and principles guiding the overall curriculum design. We highlight the appropriateness of transdisciplinary approaches to curricula focused on the sustainability field, and it distils three broad features of the two PGDip programmes that seem important – even necessary – for developing students' competencies as sustainability practitioners. These are ontological groundedness, epistemological openness and ethical attentiveness.

Significance:

This paper provides a rationale for pursuing transdisciplinary curricula that are oriented to sustainability. It shares reflections from two postgraduate diploma curriculum design processes and provides summative insights into broad features of transdisciplinary curriculum design that may enhance sustainability transitions. These features may help to guide other university curriculum developers wanting to design similar programmes to support sustainability transitions.

Introduction

Inter- and transdisciplinary learning can equip students with a nuanced understanding of global sustainability concerns while cultivating their creativity, agency and skills such as empathy and critical thinking. Such understandings and skills are increasingly recognised as necessary for addressing sustainability concerns effectively.[1-4] This paper offers a reflective conversation between the conveners of two transdisciplinary postgraduate diploma (PGDip) programmes focused on the sustainability field: the PGDip in Sustainability Transitions (PGDip:ST) at Stellenbosch University and the PGDip in Sustainability Learning (PGDip:SL) at Rhodes University. Our reflections centre around the broad question: 'What features of inter- and transdisciplinary postgraduate curricula might prepare students to participate generatively in societal transitions to sustainability?' This question is timely in that sustainability is an 'emerging academic field'[5(p.1)] that is still clarifying what kinds of orientations, pedagogies and competencies are needed for its advancement. We explore similarities and divergences between the two programmes, limiting our reflections to those of relevance to inter- and transdisciplinary curriculum design in the sustainability field. We preface the reflective part of this paper with an outline of key concepts.

Sustainability and the sustainability field

'Sustainability' is the educative focus of both PGDip programmes and the basis of other core concepts within them, such as 'sustainability transitions' and 'sustainability learning'. Across both programmes, our stance is to invite deliberation around the open-endedness of the concept rather than to pin down specific definitions. The ideal of sustainability defies traditional disciplinary boundaries and challenges long-held assumptions about knowledge, methodology and the very nature of reality. We recognise sustainability as a loaded (and increasingly over-used) concept with cultural, legal, economic, technological, political and ethico-moral implications – depending on the context in which it is applied. As noted by Ramsey[6], sustainability is a normative term that continues to elude definition because, "What appears to be an issue about clarity in language is really a set of issues about how we view and interact with the world" (p. 1076). Here, for brevity, but not denying the contested and emergent nature of the concept[7,8], we use the term 'sustainability' to refer to an ideal that shapes human actions and relationships in the environment–economy–society nexus in just, responsible and future-oriented ways.

We locate this paper in the 'sustainability *field*', recognising that the transdisciplinary nature of responding to the global crisis of unsustainability transcends 'sustainability sciences'. Our stance is guided by Wiek et al.[5] who motivate for a term with broader scope than 'sustainability science':

> *Even if used in a broad sense including natural sciences, social sciences, and humanities, other important fields addressing sustainability issues such as engineering, business, design, and planning are not sufficiently captured and recognized under the term 'science'. With the formulation ['sustainability field'], we propose to overcome all of these demarcations as the field develops its genuine program beyond disciplinary anchoring.* (p. 1)

Inter- and transdisciplinary curricula

Part of our aim is to interrogate the interdisciplinary and transdisciplinary characteristics of the two PGDip curricula and reflect on the learning possibilities that they offer. A necessary starting point is to clarify the concept of 'curriculum'. A curriculum is more than a course outline or even the sum of a programme's modules, teaching activities and assessment

practices. Rather, curriculum includes all aspects of the learning journey – explicit, tacit and hidden. Boughey and McKenna[9(p.83-84)] explain that curriculum encompasses "the what, the who, the how, and the where of teaching and learning", which are all imbued with norms and values emergent in the rich cultural history of their settings. Such a view of curriculum is important in any higher education setting but is especially significant for inter- and transdisciplinary programmes because of their emphasis on reflexivity, collaboration and engaging difference to solve real-world problems.[9,10]

Inter- and transdisciplinary curricula are now widely recognised as important and necessary, responses that equip people to respond to 'wicked problems'[11] and the global polycrisis[12,13]. Examples of sustainability challenges include climate change, poverty, drought, desertification, military conflict, biodiversity loss, social injustice, e-waste disposal and ocean acidification. What these and other sustainability challenges have in common is that they are complex, contested and contingent – features that transgress disciplinary boundaries. As such, inter- and transdisciplinary approaches require curriculum developers to make profound epistemological shifts from disciplinary and hierarchical views of knowledge towards pluralistic and dynamic views and knowledge co-production processes.[1,14] Below, we describe briefly the features of interdisciplinary and transdisciplinary curricula.

Drake and Reid[15] explain that interdisciplinarity involves making connections across established disciplines to address societal problems. Commonly, interdisciplinarity is associated with collaboration, integration and 'epistemological openness' that can help to renew, advance or exchange disciplinary knowledge.[16(p.205)]

Transdisciplinarity entails the *transcendence* of disciplinary boundaries and the integration of methodologies (academic and non-academic) for a common cause. It is associated with participation, emergence, relationality, generativity and critical and open engagement with complexity in the joint search for a new and better understanding of a problem space.[4,10,16,17] We are drawn to the openness of Vogel and O'Brien's[18] stance that transdisciplinarity is "...an approach, a process, a practice, and a capacity that draws attention to the quality of relationships. It involves being respectful of various ways of knowing and perceiving what is real. It can be considered a way of being" (p. 655). In a similar vein, Drake and Reid[15] propose transdisciplinary thinking as a critical *disposition* for building the necessary competencies for the complexities of the 21st century. They describe transdisciplinary work as being holistic, creative and relevant to real-world issues.

Although leading thinkers in transdisciplinarity, such as Nicolescu[13], Bhaskar and Hartwig[19] and Max-Neef[20], have argued for an educational revolution to enable a genuinely flourishing society and planet via transdisciplinary ways of being and doing, the literature on transdisciplinarity reflects a stronger focus on 'transdisciplinary *research*'[21-23] than on 'transdisciplinary *education*'. This is an important distinction because, although closely linked, the ways in which inter- or transdisciplinary research projects are designed and implemented in society differ from how inter- or transdisciplinary curricula are designed and implemented in higher education settings. The latter have unique features such as student learning needs, curriculum accreditation, timetables, assessment of learning outcomes and so on. Broad insights from transdisciplinary 'real-world' projects and research programmes therefore need to be *translated* into curriculum design processes with an educators' gaze.

The postgraduate diploma qualifications

Within the South African qualification landscape, the PGDip is identified as:

> generally multi- or interdisciplinary in nature but may serve to strengthen and deepen the student's knowledge in a particular discipline or profession. The primary purpose of the qualification is to enable working professionals to undertake advanced reflection and development by means of a systematic survey of current thinking, practice and research methods in an area of specialisation.[24(p.35)]

Located at level 8 on the National Qualifications Framework alongside the honours degree, the PGDip is a 120-credit qualification that offers progression into master's-level studies. Access is via a bachelor's degree or advanced diploma at National Qualifications Framework level 7.

In both PGDip programmes discussed in this paper, the developers recognised the qualification's suitability and potential to strengthen engagement with the sustainability field due to its relative flexibility in terms of disciplinary access and content. The primary rationale was to respond to the need for relational and transformational competencies in the sustainability field in South Africa.[25]

Both programmes are now briefly described before moving to the reflective section of this paper in which we consider aspects of our curriculum design experiences.

PGDip: Sustainability learning

The PGDip:SL is offered at Rhodes University by the Department of Secondary and Post-School Education in collaboration with the Department of Environmental Science. The programme was designed in 2020 to support early and mid-career professionals to understand, critique, plan and implement socially engaged learning processes that are needed for society to transition to social-ecological sustainability. The internal and national approvals and accreditation processes took place between 2020 and 2022.

As indicated by the programme's name, its core focus is on learning, which has been widely recognised as a key response to sustainability challenges. The pilot programme is currently part-time, with the first cohort of 12 students registering in 2023/2024. The students entered from diverse disciplinary undergraduate backgrounds (including Environmental Science, Economics, Politics, Sociology, Occupational Therapy and Education) and work settings (including the environmental NGO sector, higher education sector, local government and nature conservation). The unifying element across these diverse backgrounds is the programme's focus on learning (mostly outside the formal education sector), which is oriented to sustainability.

PGDip: Sustainability transitions

The PGDip:ST is offered by the Centre for Sustainability Transitions in the Faculty of Economic and Management Sciences at Stellenbosch University. The PGDip:ST aims to deepen students' understanding and knowledge of sustainable development ambitions and challenges during this time of global transition. It facilitates advanced reflection and offers both personal and professional development opportunities in the emerging fields of sustainability transitions and transformations. The PGDip:ST attracts students from diverse disciplinary backgrounds (including Public Administration, Environmental Management, Economic and Management Sciences, Political Science, Engineering, and Development Studies) and professional experience (including local government, corporate governance, construction management and the NGO sector).

The PGDip:ST curriculum was restructured in 2023 as part of an academic renewal of the existing PGDip: Sustainable Development at Stellenbosch University. This renewal retained the accredited focus and intent of the programme but included a renaming of the qualification to align with the strategic orientation around sustainability transitions. Institutional and national approvals for the proposed name change from PGDip: Sustainable Development (PGDip:SD) to PGDip:ST were initiated and progressed in 2023 and, at the time of writing, final approval is pending. For the rest of this paper, we refer to the PGDip:ST with the proviso that approval of the name change is pending.

Methodology

This paper is the outcome of an experimental exchange among academic colleagues from two South African universities who had followed separate processes to design and (re)structure transdisciplinary curricula for the PGDip:SL and PGDip:ST, respectively. In structuring this paper, we took inspiration from Kulundu-Bolus et al.[26] in their exploration of what it means to learn, live and lead in transgressive ways in a neoliberal world. Like them, we identified broad themes (in our case, themes of relevance to our interest in transdisciplinary curriculum design in the sustainability field from the context of higher education institutions in the Global South). We framed a series of reflective dialogues (online

and in-person) in late 2023 and early 2024. We had not collaborated up to this point, although two of the authors knew each other through an international research programme on transdisciplinary research that is not directly related to either PGDip programme. Our exchanges emphasised reciprocity and curiosity, and an attentiveness to what was shared and unique across the two PGDip programmes. Insights gained from the dialogues were advanced through asynchronous stretches of writing which culminated in an online sensemaking workshop to harvest insights and points of connection that form the backbone of this paper.

The sections below are the outcome of this reflective dialoguing and writing process. Sub-headings '*Megan & A'ishah*' and '*Lausanne & Jessica*' indicate the perspectives of the *PGDip:ST* and *PGDip:SL* developers, respectively. The reflections are bounded by the curriculum *design* processes and do not include experiences of programme implementation or students' learning. Reflections are arranged according to the themes that guided our initial reflections:

- Topic 1∼ Rationale, context and emergence of the programmes
- Topic 2∼ Programme structure and intended learning outcomes
- Topic 3∼ Principles guiding the curriculum design

Through the reflective dialogue process, we noted the emergence of cross-cutting themes that reflected the contextual, theoretical and ethical dimensions of the two PGDip programmes. In the concluding section of this paper, we reflect on these in more philosophical terms as the onto-epistemological and ethical dimensions of the transdisciplinary curriculum design processes. 'Onto-epistemology' refers to the intersection of our views of reality (ontology) and how knowledge is produced and shared (epistemology). 'Ethical' refers to principles or guidelines about what is morally right and acceptable, which is an important aspect of curricula so explicitly oriented to sustainability. Although we do not use these philosophical terms when reflecting on Topics 1–3, readers may be able to identify and trace these aspects before we return to them in the conclusion.

Topic 1: Rationale, context and emergence of the programmes

Common to both programmes was the motivation to make further study opportunities in the sustainability field available at our respective universities, and to do so with an emphasis on the Global South. The global polycrisis[12] necessitates a substantial reorientation of (higher) education[27,28], and global, national and institutional drivers created a shared impetus for curriculum development that made an inter- or transdisciplinary approach compelling. Critiques of the global higher education system from a Global South perspective emphasise the importance of paying attention to issues related to decolonization[29], knowledge democracy and epistemic justice[30,31] and paying attention to issues of intersectionality, diversity and difference[3].

Although technical competencies are most commonly associated with the sustainability field, Rosenberg et al.[25] report the need for greater focus on relational and transformational competencies in South Africa's transition to a green economy. The curriculum designers at both universities recognised that the form and function of the PGDip qualification in the national qualifications landscape offered potentially connective, interstitial and bridging curriculum opportunities to innovate in that area.

Lausanne and Jessica

The primary rationale for creating the PGDip:SL was to respond to the need for relational and transformational competencies in the sustainability field in South Africa[25], in particular, competencies linked to enabling informal and non-formal education and training. Many professionals working in the sustainability field are mandated to plan and provide learning programmes, but they are not (and do not seek to be) qualified as schoolteachers or university lecturers. However, there was no coherent study pathway for such graduates and practitioners to strengthen the educational dimension of their work. A similar and significant gap exists for entry-level practitioners at National Qualifications Framework level 4 (equivalent to a secondary school certificate or a vocational certificate) and National Qualifications Framework level 5 (equivalent to a higher certificate, diploma). As a small, research-intensive university, we recognised that we could not respond to both gaps and that pursuing the PGDip:SL would be appropriate and achievable within a research-intensive university.

We conducted an online feasibility survey in 2020 which confirmed there was interest and support for the diploma, both within Rhodes University and in the sustainability field. From the survey, we identified several broad knowledge and skills areas which the diploma should address for it to be responsive to the needs of the field:

1. systems thinking and ability to take a complex systems approach to planning and implementing sustainability learning processes;
2. inter- and transdisciplinary thinking skills;
3. critical thinking (embedded in critical reading and writing skills);
4. social learning and related theories and methodologies to support learning;
5. theoretical and conceptual underpinnings of sustainability;
6. research skills, especially community-based, engaged, action-oriented research in local settings;
7. facilitation, communication and leadership skills; and
8. ethics, equity, embodiment and empathy in engagement.

In naming the programme, we recognised that 'learning' rather than 'education' would better reflect its aim to support practitioners working (in most cases) outside the formal education sector. We chose 'sustainability learning' as a compendium term to encompass the more established nomenclature (Environmental Education [EE], Education for Sustainable Development [ESD], Sustainability Education [SE], Environment and Sustainability Education [ESE]) while explicitly acknowledging that learning processes oriented to sustainability transitions are not confined to formal education settings. Most practitioners in the sustainability field need to engage with complex social change processes that are entangled with dynamics of knowledge, power and agency, yet they do not identify as being 'educators' per se. Our intention was for the subtle shift in language (from education to learning) to be more resonant and inviting for practitioners in the sustainability field.

Megan and A'ishah

The PGDip:ST's emergence over nearly two decades is an example of the adaptability of transdisciplinary programme development in relation to institutional structures. The programme has been in existence at Stellenbosch University since 2006, known initially as the PGDip in Sustainable Development, Planning and Management, and later as the PGDip in Sustainable Development, located within the School of Public Leadership. In 2015, the Centre for Sustainability Transitions was established as a flagship research centre in the School of Public Leadership, with an explicit commitment to transdisciplinary research, complexity theory and sustainability science. In 2021, the Centre became a type-2 research centre, the equivalent of a department, within the Faculty of Economic and Management Sciences. The following year, all three postgraduate programmes in sustainable development (PGDip, MPhil and PhD) were migrated to the Centre, and an academic renewal process was initiated to reflect on their curricula. This was an opportunity to update the content and structure of the PGDip to ensure a cutting edge, globally relevant offering in sustainability transitions, as well as to align and integrate the Centre's transdisciplinary sustainability science research programmes with the PGDip curriculum. The programme renewal process affirmed the importance of an introductory course in sustainability transitions and sustainable development. The PGDip's carefully curated and facilitated learning experiences provide unique opportunities for students wanting to pursue postgraduate studies but not yet ready to commit to the more extensive and self-directed research of a master's programme.

Topic 2: Programme structure and intended learning outcomes

Table 1 presents the intended learning outcomes of each PGDip programme and, in the second column, an overview of the course/module names with their credit weighting.

Table 1: Learning outcomes and structure of the two qualifications (PGDip:SL and PGDip:ST)

Learning outcomes	Course structure and content*
PGDip: Sustainability Learning	
By the end of the two-year part-time PGDip:SL programme, learners should be able to:	*Course 1:* Foundations of Sustainability Learning [50 credits**]
1. engage critically with a range of perspectives on sustainability, sustainable development and sustainability learning;	• Module 1.1: Sustainability Concepts and Critique [10]
2. compare, contrast and apply diverse approaches to systems thinking;	• Module 1.2: Systems Thinking: History, Context and Future [10]
3. make connections between the political history of knowledge production and contemporary challenges in sustainability learning;	• Module 1.3: Interdisciplinarity, Knowledge and Power [10]
4. reflect critically on, and apply, social learning praxis to social-ecological sustainability;	• Module 1.4: Participation, Solidarity and Sustainability Ethics [10]
5. understand and apply interdisciplinary social science research methods;	• Module 1.5: Introduction to Social Learning Processes [10]
6. plan, implement and report on a sustainability learning action research change project;	*Course 2:* Introduction to Interdisciplinary Social Science Research*** [10 credits]
7. reflexively apply context-appropriate evaluation methods and processes; and	*Course 3:* Action Research Change Project [30 credits]
8. develop reflexivity through relational and critical thinking in their own sustainability learning practice and context.	• Module 3.1: Describing Sustainability Learning Contexts [10]
	• Module 3.2: Envisioning Change for Sustainability [10]
	• Module 3.3: Enacting Change for Sustainability [10]
	Course 4: Evaluation as Learning [10 credits]
	Elective Courses (students select ONE course from Elective A options, and ONE from Elective B)
	Elective A [10 credits]
	• Option 1: Creative Practice for Sustainability Learning
	• Option 2: Citizen Science for Sustainability
	Elective B [10 credits]
	• Option 1: Climate Change Education and Governance
	• Option 2: Building and Sustaining Multi-stakeholder Learning Networks
	(Elective options may vary from year to year based on student profiles and availability of collaborators).
PGDip: Sustainability Transitions	
By the end of the one-year full-time or two-year part-time PGDip: ST programme, learners should be able to:	*Module 1:* Sustainability Transitions and Transformations [15 credits]
1. identify, describe and analyse key historical and current global economic, political and ecological trends driving global change at multiple scales that culminate in a sustainability polycrisis;	*Module 2:* Complexity Literacy and Systems Worldviews [15 credits]
2. distinguish and apply different perspectives and frameworks on multi-level dynamics of change and how these coalesce into relational and dynamics perspectives on sustainability transitions and transformations;	*Module 3:* Biodiversity and Climate Change [15 credits]
3. critically evaluate and cultivate divergent South African, African and global interpretations of theoretical and practical approaches to sustainable development, considering how these approaches address issues of justice, equity and human-nature connectedness within social-ecological systems to develop more inclusive and effective strategies for sustainable development;	*Module 4:* Financing Just Energy Transitions [15 credits]
4. develop effective strategies for initiating social processes that bring diverse stakeholders together for transformative action on social, political and environmental causes, applying systems thinking;	*Module 5:* Water and Food Nexus [15 credits]
5. cultivate skills of reflection, reflexivity, empathy, curiosity, negotiation and experimentation with diverse groups of actors in collaborative learning processes, navigating the intricate ethical and social dimensions of sustainability issues.	*Module 6:* Just and Sustainable Urbanisms [15 credits]
	Module 7: Governance and Institutional Change [15 credits]
	Module 8: Leadership for Sustainability Transitions and Transformations [15 credits]

** There is international and institutional variability in naming the parts of a learning programme. The PGDip:SL arranges the curriculum by 'courses' composed of smaller 'modules'. The PGDip:ST uses smaller 'modules' throughout.*

*** One credit is roughly equivalent to 10 notional hours.*

**** Social science research methodology is considered appropriate for the educational focus of the PGDip:SL, laying a foundation for the subsequent Action Research Change Project course.*

Megan and A'ishah

The renewed PGDip:ST curriculum reflects the core thematic research areas of the Centre for Sustainability Transitions at Stellenbosch University: (1) knowledge co-production, (2) social-ecological resilience, (3) transformative future thinking, (4) finance and resource flows and (5) political economy and development. These articulate across a wide range of empirical research fields and areas of activities, including education and training, research, and engagements across the science-policy-practice interface. The diploma's eight integrated modules are enriched by these transdisciplinary research areas and case studies that speak to the heart of the global polycrisis. The aim is for students to develop their understanding of the Anthropocene polycrisis as the culmination of multiple, historical and intersecting crises across diverse domains. As shown in the selection of learning outcomes in Table 1, students should, by the end of the programme, be able to discern, co-design, lead or facilitate appropriate interventions to mobilise social change across diverse personal and professional settings.

Collaborative learning processes across the eight modules cultivate deep skills of reflection, reflexivity, empathy, curiosity, negotiation and experimentation. The assessment framework entails a variety of individual, reflective, analytical and collaborative elements that meet a variety of assessment purposes. Importantly, the final module in the programme, 'Leadership for Sustainability Transitions and Transformations', is positioned as a capstone module that supports programme-level assessment. Here, students develop a range of group and individual assignments that culminate in a portfolio of evidence, linking their overarching learning experience in the programme.

Lausanne and Jessica

Since the start of our curriculum design journey, we have grappled with the question of whether the PGDip:SL is an inter- or transdisciplinary programme. This is evident, for example, in the naming of some modules (see Table 1): 'Interdisciplinarity, Knowledge and Power' and 'Introduction to Interdisciplinary Social Science Research', yet we consider the overall programme to be transdisciplinary. Our view is that the PGDip:SL curriculum has many features of interdisciplinary curricula that are in service of the overall learning outcomes which are for students to do educative work in transdisciplinary settings. The programme is conceptually and administratively anchored in the discipline of education, yet it draws on other disciplines (a feature of interdisciplinarity) so that students can investigate, critique, dream and innovate in the authentic problem spaces of their own work or community contexts (a feature of transdisciplinarity).

We are also cautious to avoid dismissing interdisciplinary curricula as inferior to transdisciplinary curricula without more detailed and careful consideration of the ways in which pedagogy, assessment and the institutional framings of postgraduate-level studies interface with knowledge production and real-world application. This requires further research with our students and critical friends, but our preliminary insight is that some interdisciplinary elements within a transdisciplinary curriculum can usefully scaffold learning and guide students towards transdisciplinary applications – bearing in mind the point made earlier that the considerations when designing and implementing transdisciplinary *research* programmes and transdisciplinary *teaching* programmes are not necessarily interchangeable. For example, the sequencing of the courses 'Foundations of Sustainability Learning' and 'Introduction to Interdisciplinary Social Science Research' before the 'Action Research Change Project' reflects our intention to scaffold students' progression from bite-size encounters with a range of concept-laden modules (an interdisciplinary moment) into the design and implementation of an action research project in their own work or community setting (a transdisciplinary moment).

Integrated reflections

Through our reflective dialogues, and evidenced in the course and module names, we identified numerous concepts and curriculum features common to both programmes. These include:

- relational thinking
- complexity
- a justice orientation
- working out of/into an authentic context
- reflexivity
- social change
- collaboration / participation
- past–present–future connections

There is general agreement among scholars that transdisciplinary curricula must include opportunities to learn about and solve real-world problems[1,10] by "thinking from the life world, beyond disciplinary boundaries"[32]. In both PGDip programmes, we have structured the course of learning around transdisciplinary questions. For the PGDip:ST, we ask: How do we engage with the dynamics of change for sustainability transitions at multiple scales? And for the PGDip:SL, we ask: What kinds of learning processes are needed for society to transition to social-ecological sustainability? Case study methodology (including field trips, excursions and guest presenters) is central to exploring these questions. This design decision echoes Scholz and Steiner's[33] insight that case studies have educative value in transdisciplinary learning processes because, "they embody the complexity, multi-layeredness of tradeoffs and conflicts, uncertainty, and incompleteness, which relate to any form of scientific knowledge for which real-word contexts and -structures are the underlying basis" (p. 528).

Topic 3: Principles guiding curriculum design

Principles that guide the design of any curriculum, research programme or sustainability project are traceable to an underlying philosophy and set of assumptions on whether the people involved are aware of it. McGregor[32] notes that transdisciplinary curricula require a distinctive educational philosophy characterised, for example, by:

- recognising education as an active, generative process that exists in a synergistic relationship with society;
- understanding that learning is a complex, dynamic and unscriptable process that involves mind, body and soul;
- seeking unity of knowledge over disciplinary fragmentation;
- paying attention to relational and cognitive processes such as critical thinking, integrated thinking, change management and respect for diversity and tolerance.

These characteristics resonate strongly with the values and intentions guiding our emerging curricula. Below, we outline six guiding principles that, through our reflective dialogues, we found were common to both programmes.

Teaching and learning as transformation

The design of both programmes was anchored in an explicit intention to catalyse positive change at a personal and local level, and/or a broader social-ecological level. We were guided by the principle of exploring teaching and learning processes that hold genuine transformative potential. In this, we were influenced by an expanding and diverse body of scholarship that points towards socially engaged, ethics-oriented, dialogical and emancipatory learning processes underpinned by critical thinking skills, empathy, relationality, creativity, reflexivity and individual-collective agency. Elaborations of work in this area include Orr[27], Jickling et al.[34], Kulundu-Bolus et al.[26], Eames et al.[35] and Lotz-Sisitka[28].

Relational thinking

Transformative and transgressive learning processes can only exist within a relational philosophy. Lejano[36] defines relationality as "the degree to which individuals understand their being, thought, and action as integrated with that of others and, so, make decisions and take action in ways responding to these relationships" (p.109). Relational thinking is a crucial principle of transdisciplinary curriculum design because it invites "informed critical reflection"[10(p.12)] strengthens lifeworld knowing[32] and develops ethical sensibilities[34]. Relationality is also fundamental to the sustainability field because it makes explicit our rootedness in, and complete dependence on, the natural world and planetary systems. In

both PGDip programmes, relational thinking is evident in the multi-modal pedagogies and in the construction and naming of courses and modules (see Table 1).

Contextual relevance

A contextually relevant curriculum is one that resonates with students' lifeworlds and supports them to make meaningful connections across micro, meso and macro contexts. This commitment challenges us to create learning spaces that can engage simultaneously with: (1) the scale and urgency of the planetary crisis, (2) students' lived experiences, identities and disciplinary backgrounds and (3) the complex and contested socio-politico-economic and ecological settings in which they are developing their professional competence.

Developing applied competence or praxis

Both programmes were strongly oriented around learning processes that enable students to respond reflexively to real-life problems in the context of the national and global polycrisis. In the PGDip:ST, this is referred to as praxis, engaging students as co-creators of knowledge, actively engaging them in integrating theory and practice. In the *PGDip:SL*, this was articulated as applied competence, "the union of practical, foundational and reflexive competence".[37(p.20)] This requires a curriculum to achieve a balance between supporting students to (1) *understand* concepts, theories and terminologies underpinning their studies, (2) *apply* that understanding to their context in practical and authentic ways, and (3) *reflect* on their practice with a view to sustaining or improving it. Developing praxis or applied competence is a prerequisite to two other important principles introduced below: activating human agency, and a curriculum rooted in the context of the Global South.

Activating individual and collective agency

Many students apply to join the PGDip programmes because they seek to resolve sustainability concerns in their communities or workplaces. Mobilising such change processes requires the activation of individual and collective agency, that is, the capacity of individuals and groups to collaborate, co-imagine and partner in support of shared goals. Equally, acting on one's agency also requires navigating tension and disruption. To this end, we aim for a curriculum that nurtures students' resourcefulness, self-awareness and creativity, and cultivates an enlivened sense of how positionality, power, justice and equity inform how, where and with whom they act. This requires a curriculum orientated to inner growth and transformation as much as broader social-ecological change. We draw inspiration from frameworks like the Inner Development Goals[38] that explore various skills across dimensions of being, thinking, relating, collaborating and acting in support of sustainability.

Curriculum rooted in the Global South

This principle refers to the aspiration to infuse the curriculum with resources, case studies and theories that reinforce an African and Global South perspective. Rootedness in the Global South means working towards cognitive and epistemic justice. This requires paying critical attention to the kinds of knowledge that are treated as valid[39,40], for example, by working with indigenous knowledge and knowers, Global South theorists and philosophers, and confronting the hegemony of academic and scientific knowledge in higher education. Our curricula therefore aim to contribute to creating an environment where students from a diversity of contexts and backgrounds feel welcome and valued. We aim to enable knowledge production that is change-oriented and empowers students and other participants as changemakers to enable them to address deep-seated sustainability and social justice issues. This principle is therefore relevant not only in the context of Global South higher education institutions but can add value to curricula around the world, especially in the context of rapid globalisation and the growing emphasis on internationalisation in higher education, where it is becoming necessary to "recognise the epistemic plurality of the world".[41(p.33)]

Concluding insights

At the start of this paper, we discussed the significance of transdisciplinarity for the sustainability field, noting that transdisciplinarity is more like an approach and way of being than a knowledge production strategy. Transdisciplinarity's defining feature, the transcendence of disciplinary boundaries orientated to real-world problem-solving, offers new and promising approaches to the sustainability crisis. Within that, transdisciplinary curricula offer distinct educative responses that differ in some ways from transdisciplinary *research* programmes due to the primacy of student learning when thinking about curriculum design.

We conclude by offering a summative reflection across three broad features of our PGDip programmes: ontological groundedness, epistemological openness and ethical attentiveness. The sustainability field exists due to tensions and misalignments at the interface of ontology, epistemology and applied ethics. Ontologically, the planet is in a state of escalating polycrisis. Our conceptual repertoire and the patterns of knowledge production and dissemination (our epistemologies) influence how we investigate, understand and represent these realities with students. The sustainability field is also strongly normative in that it makes distinctions between just/unjust scenarios, desirable/undesirable futures and so on. This raises ethical questions that need to be built into curricula from the design stage, such as: Who is responsible for enacting the needed change? And does nature have moral rights?

We set out to answer the question: What features of inter- and trans-disciplinary postgraduate curricula might prepare students to participate generatively in societal transitions to sustainability? Our reflections across Topics 1–3 suggest that ontological grounding, epistemological openness and ethical attentiveness are important features of inter- or transdisciplinary curriculum focused on sustainability. These features and some associated teaching methodologies are offered in Table 2.

These curriculum features are necessarily broad, leaving room for contextual adaptation and nimbleness in uncertain times. They are also interrelated and mutually supportive, meaning that the coherence of curriculum design would be undermined if the ontological, epistemological and ethical features are not pursued in unison. The illustrative examples of related teaching methodologies and pedagogies provided in column 2 of Table 2 are also consistent with the guiding curriculum principles previously discussed, namely, teaching and learning as transformation, relational thinking, contextual relevance, developing applied competence/praxis, activating agency and curriculum rooted in the Global South.

Transdisciplinary learning in service of sustainability transitions can be realised in higher education through intentional curriculum design. Based on our initial curriculum design experiences (but not yet the

Table 2: Broad features of transdisciplinary curriculum design for PGDip programmes focused on sustainability

Broad curriculum feature	Examples of supporting teaching methodologies and pedagogies
Ontological grounding	Contextually situated learning via case studies and local field trips and excursions; work-integrated assignments; action research projects; orientating to complexity and systems thinking; engaging Global South scholarship; robust knowledge inputs via experts and quality literature.
Epistemological openness	Dialogicality; knowledge co-construction and critique (group tasks); participatory methods; diversity in teaching and assessment methods; engagement with diverse knowledge systems and representations of knowledge.
Ethical attentiveness	Relational and empathetic encounters; reflexive practices; inner development and values clarification; embodied practices; deliberation and critique.

implementation experiences), we have shared thematic reflections and offered three complementary features that may be of value to colleagues in higher education who are curious, inspired or compelled to explore the possibilities of transdisciplinary curricula in a world at risk.

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Data availability

Data pertaining to the PGDip programmes' curricula are available at the relevant institutions upon request.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare.

Authors' contributions

L.O.: Conceptualisation, methodology, data collection, data analysis, validation, writing initial draft, writing revisions, project leadership, project management. M.D.: Conceptualisation, methodology, data collection, data analysis, validation, writing initial draft, project leadership. A.E.: Conceptualisation, methodology, data collection, data analysis, writing initial draft. J.C.: Conceptualisation, methodology, data collection, data analysis, writing initial draft. All authors read and approved the final version.

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Skills for the just energy transition: Is skills research 'on track'?

There is widespread agreement that skills development is a vital dimension of the just energy transition (JET). Skills development for JET is rapidly emerging and involves complex inter-sectoral systems of skills development and new methods for demand analysis. Currently in South Africa, learning pathways into green jobs, enterprise development and more sustainable job options, including those required for JET at entry and technical levels, are unclear, ad hoc and fragmented. At best, we have fragmented offerings of courses and qualifications and few systemic approaches to skills analysis and development. There is also a narrow reliance on supply and demand discourses that are ill-fitting for the type of skills that need to be developed. Drawing on a group of regional and local studies focusing on skills supply and demand for JET, the paper analyses the responsiveness of skills systems, with specific focus on institutions and institutional arrangements that underpin skills planning and anticipation. The paper critiques the metaphor of 'supply' and 'demand', which, it argues, is the wrong lens, as it focuses attention on certain parts of the skills system dislocated from the broader conditions that they are imbedded in. We pose new methodological questions for engaged skills research that can enable a green and just future, and the systemic transformations that are needed to catalyse a low-carbon transition.

Significance:

The research findings offer a critical reflection on the current approach to research focused on skills for the just energy transition. The review highlights the limitations of the dominant supply-demand approach of skills analysis, and we argue that it promotes a neoliberal, market-led discourse on skills that privileges industry and excludes the voices of communities and workers.

Introduction

The transition of the energy sector is broadly regarded as an important socio-technical change that links people-technology-ecological relationships in relation to broader systemic issues, such as rising energy costs, energy insecurity and pressures to decarbonise. Skills are seen as one of the main drivers to achieve a just energy transition (JET). For skills to become central in transitions, and in a green and just recovery, the identification, anticipation and provision of relevant skills is crucial. This paper hence unpacks the nub of the dilemma in raising questions on the way current JET skills research is being conceptualised and executed. We argue that the dominant research approach is framed within a skills demand and skills supply narrative and that, given the scope of the transition, it is wholly insufficient.

We further argue that current studies reviewed have been shaped by a neoliberal ideology and that transitions to low-carbon economies are experienced differently by different stakeholders and perceived as complex and contested. This creates rapidly changing knowledge contexts that require a revitalised approach to how skills development can be conceptualised and implemented, and as espoused by Green and Gambhir[1], there needs to be a strong focus on retraining affected workers to facilitate labour market adjustment and on on-the-job retraining.

We then argue that conceptualising skills for JET requires a framework that moves beyond the individual, to organisations and systems with the purpose of jointly fostering systemic change and counteracting pervasive entrenchments that keep us trapped in unsustainable linear and siloed practices. Skills development that supports these transitions will only be realised when reciprocity is established between various stakeholders including employers, workers and communities within which a business operates.

The just energy transition in South Africa

JET in South Africa is and will have a major impact on the current energy system (including distribution to industry and local communities).[2–4] Aside from being fossil fuel dependent, the country's economy is energy-intensive – with the energy sector contributing 95% of South Africa's total CO_2 emissions in 2020.[4] It also faces significant disruptions to energy supply through enforced power outages, which are compounded by increasing energy costs.[5] Given these challenges, there is a recognised need to shift away from fossil fuels and to improve the resilience of the energy system through the diversification and decarbonisation of the electricity sector and to optimise energy usage.[5] The government has a net-zero emissions aspiration by 2050, with shorter term targets of 398–510 Mt CO_2-eq per year for 2021–2025 and 350–420 Mt CO_2-eq per year for 2026–2030.[4,6] Concurrently, there is a drive for expansion into new domestic and export markets, like green hydrogen.[7]

Literature review

Clarifying what a transition to a green economy is, is important to the core argument of this paper. If the transition to a greener economy is understood as an economic development strategy that "results in improved human well-being and social equity, whilst significantly reducing environmental risks and ecological scarcities"[8(p.16)], then simply removing high-carbon industrial activities for an energy transition would be insufficient. Greening the economy would therefore mean that jobs created through a green and/or energy transition should be 'decent', whether a 'green job' or not, with reasonable terms and conditions. We draw on the United Nations Environment Programme's

(UNEP)[8] notion of decent green work as adequate wages, safe working conditions, job security, skilled and satisfying work and worker voice.

Montmasson-Clair[9] argues that a just transition contains key elements that are pivotal for inclusive decent work and encompasses the elimination of inequalities. A just transition places emphasis on the incorporation of marginalised groups such as women, youth and people living with disabilities in decision-making processes. Some authors[10,11] do, however, caution that an overriding theme of transformative strategies is that they tend to depend on entry-level skills, that offer low wages and hence pose the risk of enhancing existing inequalities. This highlights the need for precise objectives related to the creation of decent green jobs as sustainability transitions take place.[10]

Skills in this paper are used to refer to the knowledge, expertise and the capacity to conduct work. While we believe that this definition has its limitations seen through the simplification of a complex theoretical and empirical concept, this meaning of skills is widely used in policymaking and implementation. Skills development plays a crucial role in seizing opportunities and unlocking the potential for reimagining jobs and work in JET. Drawing from the green skills framing[12], these skills could be viewed as 'the abilities, values and attitudes people need to build and support a sustainable and resource-efficient society'. Green skills therefore need to result in "improved human well-being and social equity, whilst significantly reducing environmental risks and ecological scarcities"[8(p.16)]. Thus, skills for JET are multidimensional and are not solely linked to technology and improved productivity but also include strong social, environmental and public imperatives and cover work, learning and community contexts. Therefore, these skills carry not only the key to unlocking renewable energy industries but also the potential to promote equity and social inclusion under an alternative version of sustainable economic growth. Green and Gambhir[1] also emphasise the need for capacity to steer long-term, participatory, cooperative processes that empower diverse local actors to recombine their existing knowledge, skills and competences in new ways to broker dialogue and reconfigure knowledge networks and engage in activity that shifts cultural norms and worldviews.

Skills to support greening are also not homogeneous. This has methodological implications for how green skills research is designed, structured and who the central actors are.[13] The skills needed for the transition need to be viewed as a continuum (Figure 1); at one end, green skills are understood as skills to green work (e.g. the work of engineers, electricians and scientists) and skills that are directly linked to jobs and as such central to the jobs at the core of transitioning the economy. At the other end of the continuum are more transformative skills and competencies that are meant to disrupt the *status quo*, such as transformative systems thinking and analysis of unequal systems of power. Figure 1 further shows that nestled between these two ends are core life skills that are central to a transition, such as empathy, resilience and collaborative thinking.

It has been argued that skills approaches within the green transition are often critiqued for being conceptualised as skills for green jobs, framed through a 'skills gap' and 'skill deficit' argument, reminiscent of human capital approaches.[14] The critical challenge with this position is that it presents a linear relationship between education, skills, and the economy. Its neoliberal framing defines the purpose and relevance of education and skills in terms of how it serves the market and hence locates skills within the traditional economic discourses. This approach perpetuates the idea that market-responsive skills development will solve broad developmental problems, that is, what jobs and skills are needed by the market, and therefore, what skills should be taught? Allais[15] and Balwanz and Ngcwangu[16] argue that this conceptualises skills development in a reductive and instrumental frame.

Looking more broadly beyond 'skills gaps', there exists a belief that skills formation should not only have a business-centric influence, as this negates the socio-economic needs of workers and communities. It has also been argued[10] that these economically framed skills responses place little emphasis on skills systems holistically. This leaves skills development and training to private providers who operate within a reactive and short-term nature that presents potential sustainability pitfalls. Further, there are arguments that see skills as needed in one place and produced in another rather than "society and an economy as an organism of which skill formation is a complex set of moving parts, shaped by the economy and how different spheres of society interact with each other"[15]. We draw on Allais's[15] argument that the metaphor of 'supply' and 'demand' is the wrong lens, as it directs our attention towards siloed aspects of the skills system minus considering broader structural elements.

Overview of empirical work

This paper draws on different empirical studies undertaken by the Centre from 2022 to the present. All respond to skills demand and supply linked to South Africa's energy transition and include:

a) The South African Energy Skills Roadmap (2023)[5] which sought to identify energy-related skills to facilitate an energy transition for the country. Data collection included the analysis of 200 energy research documents, a review of over 700 energy jobs, a trend and future scenarios analysis, interviews and validation workshops.

b) Research undertaken on Installation, Repair, and Maintenance (IRM) skills ecosystem: Atlantis[17] focused on understanding the interconnected factors and stakeholders that influence IRM skills acquisition and utilisation to inform the development of a skills training hub to support township-based Small, Medium and Micro Enterprises (SMMEs) and to build green economy pathways for

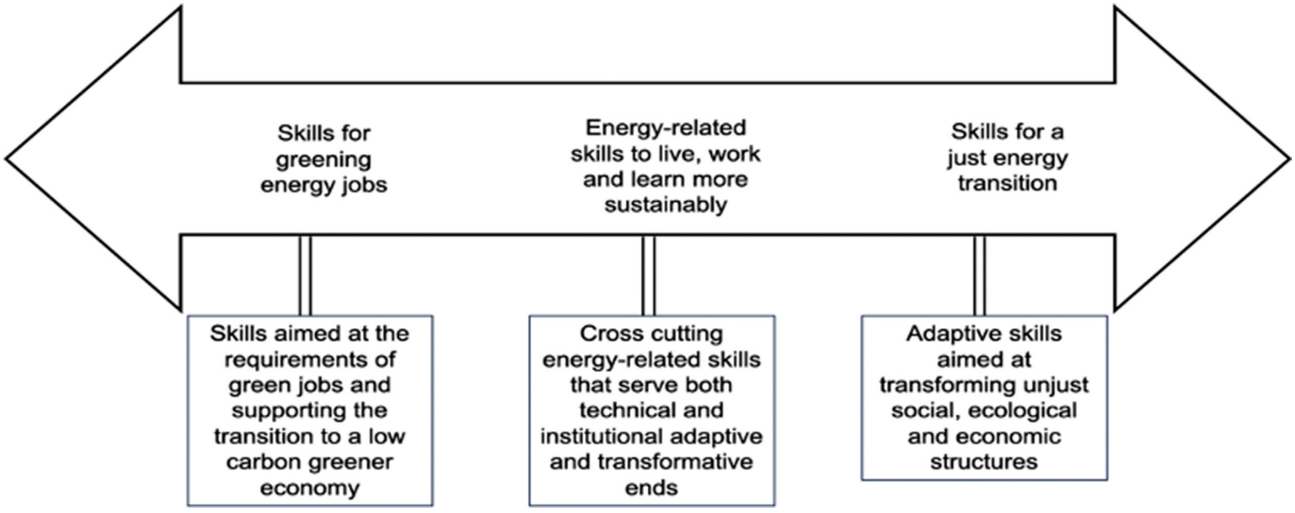


Figure 1: Skills for a just transition as a continuum.

youth. Data were collected through 58 interviews, 5 focus groups with local learners and unemployed youth, a survey with 2763 IRM users and a stakeholder workshop.

c) Research undertaken to understand the key leverage points in the food and beverage manufacturing sector to enable a low-carbon transition.[18] The purpose of the energy hotspots research was to identify the main areas of energy impact and challenges across different food and beverage manufacturing sub-sector value chains, such as baking and dairy to inform where the greatest need is for occupations to mitigate these impacts. This research further informed studies on skills required for an energy transition in the baked goods sector in the City of Ekurhuleni and the fish and seafood sector in the Table Bay area in the City of Cape Town.

In addition to these core studies, insights are also informed by two pieces of research undertaken for the International Labour Organization (ILO) on skills supply and demand for renewable energy, energy efficiency and regional energy integration in the Southern African Development Community (SADC), which included South Africa[19], and a skills needs assessment of renewable energy in Mauritius, and the circular economy in Seychelles[20].

Skills to support the just energy transition

The notion of a demand-led approach for skills dominates discussions on the energy transition. This is centred on the notion that skills shortages and mismatches between employer demand and education system supply are because of inadequate information about labour market demand.[15] The findings below highlight some of the key insights around skills supply and demand to support an energy transition.

Demand context: Skills expectation and labour market analysis

The data illustrate that core energy trends are driving changes in jobs in South Africa. The most significant trends identified are an increase in energy costs, unstable electricity supply, a drive to decarbonise economic activity and the automation and electrification of sectors. This in turn results in an emphasis on activities to reduce costs, including improved energy efficiency and optimisation, and a shift to renewable energy technologies.[5,21] These trends not only impact on the reorganisation of how energy is generated and distributed, for example, an increase in decentralised renewable energy technologies results in a need for smarter grids and grid expansion, but also require changes to existing jobs, and potential job losses due a shift away from fossil fuels, and/or a requirement for new jobs.[5]

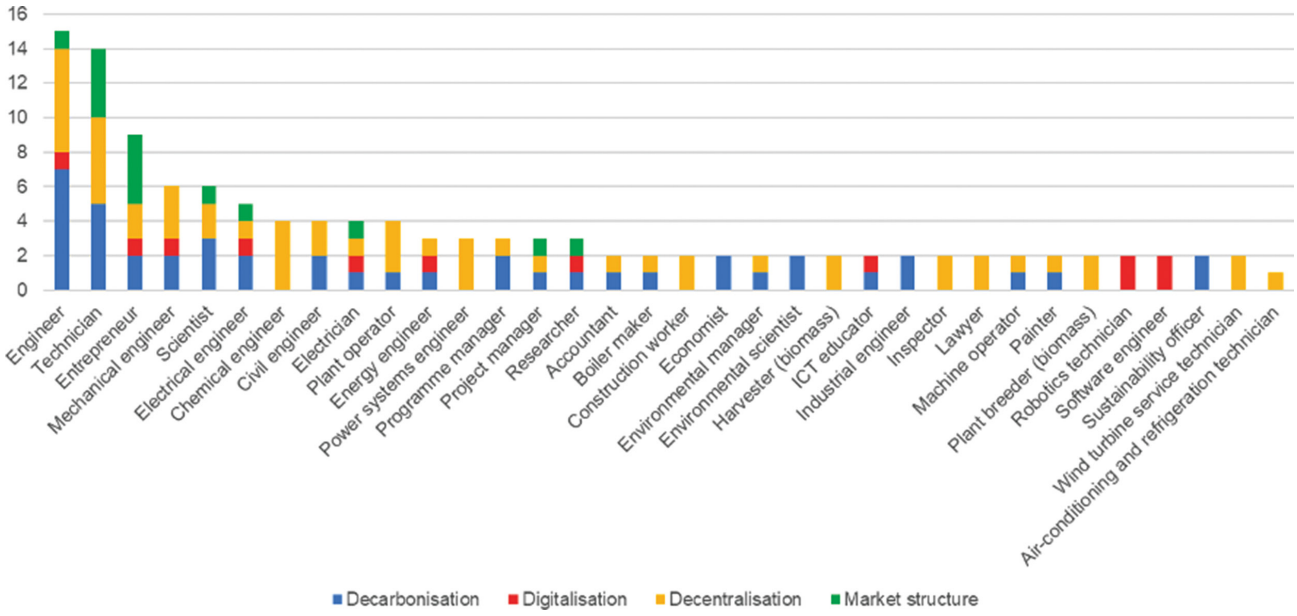
This study further suggests that in response to changes in technology and job requirements, emphasis is being placed on technical jobs and skills, as most solutions proposed in policy and by industry are techno-centric.[5] In addition, it was found that descriptions of jobs required are generalised, for example, it is common to indicate that engineers and technicians are needed, but little detail is provided on the type of engineer or artisan.[5]

When specific jobs or skills are mentioned, these again are mainly focused on technical and tend to emphasise those that are (1) likely to be lost through a shift away from fossil fuels, such as coal miners and transporters[9,22], or automation, such as electricity-sales tellers[23], (2) related to specific renewable-related technologies such as solar, wind or green hydrogen[5,17,18] or (3) responding to a critical need to maintain and repair machinery and energy-related infrastructure[5,18].

This technical emphasis is highlighted in Figure 2, which illustrates some of the core occupations identified through the development of South Africa's skills energy roadmap.[5] It highlights the main jobs cited in a review of South African energy-related policy, initiatives, research and energy intervention reports. The most prominent and commonly cited jobs are engineers (notably electrical, mechanical, civil, power systems and chemical), scientists and data professionals (such as energy specialists) and technicians (such as electricians, forepersons, and maintenance and plant managers).

What is evident is that much emphasis is placed on high-level and some intermediate jobs, with minimal mention of entry-level jobs. For example, research undertaken for the Food and Beverage Manufacturing Sector Education and Training Authority (FoodBev SETA) clearly indicates that core occupations required to mitigate energy consumption and decarbonise the sector are senior managers (such as finance and operations), and electrical, mechanical and renewable energy engineers and technicians. With technicians being further identified as those involved in, for example, maintenance of solar photovoltaic (PV) plants, air conditioning and refrigeration, diesel mechanics and machine operation.[17,18,21]

While the studies clearly illustrate an overarching need for technical jobs and skills, most research respondents did, however, acknowledge that there appears to be an adequate supply of the more 'traditional' technically qualified individuals, such as electrical engineers and electricians



Source: South African National Energy Association[5] (reproduced with permission)

Figure 2: Occupations identified through a review of energy-related documents to inform South Africa's energy skills roadmap.

(except for 'heavy' current).[18,21] However, while these more traditional technical skills are available, it is specialist knowledge and skills that are in demand, for example, in wind, biomass and green hydrogen[20,21] or where sectors are becoming less attractive to new work entrants, such as the fishing industry, in which case marine engineers are identified as a scarce, critical job.[21] Respondents suggested that while this lack of skills does not necessarily require the need for new qualifications, jobs are changing, and there is, therefore, a need for the upskilling of the current workforce to enable a JET. To echo this sentiment, Martinez-Fernandez et al.[24] affirm that as sectors and production processes transition, traditional (existing) skills of the low- to middle-skilled occupations representing entry and intermediate levels will need to be enhanced by green skills to align with emerging labour markets.

Furthermore, there were numerous examples of transforming jobs, such as chief financial officers requiring new knowledge of different renewable technologies to make informed investment decisions, or electrical engineers requiring upskilling for the design of solar PV systems.[5,21,25] This is also the case for green hydrogen – a new technology – but encompasses renewable energy occupations as well as chemical engineers that will specialise in the various processes required for the production of green hydrogen and PtX products.[5]

The studies also indicate that while a significant increase in jobs in alternative energy is expected, the type of jobs may be different. For example, construction and installation jobs will be required at the onset of renewable energy projects but less so in the operations and maintenance phase of plants.[5] Christiaensen et al.[26], in a study of the Silesia region, similarly found that the absorption of affected employees into emerging industries such as renewable energy is challenging due to various reasons such as the inability of solar PV plants to offer sustainable employment beyond the construction phase. Importantly for South Africa, this highlights that some of the skills challenges are linked to the nature of transitions and not necessarily geographic location. Additionally, those involved in renewable energy policy development are most in demand in the short term as strategies are being developed and should drop off over the next 10 years as policy is implemented.[5] The research also highlights that while energy transition jobs are required across the public and private sectors, the private sector is driving the demand for alternative energy skills (due to a response to deliver renewable energy solutions, or to provide advice to industry), while government remains focused on more traditional occupations, such as electrical engineers.[5]

This recognition of community alludes to a more holistic approach to the energy transition, and the need for more than just technical solutions, jobs and skills. From this perspective, the studies undertaken by the Centre aimed to explore the additional non-core energy jobs and skills required to enable a transition. Skills identified through this process highlighted a need for skills related to policy development, regulation, business development, procurement, environmental and social sustainability, human resources and community engagement.[5,19–21] This recognition of a broader scope of 'supporting' skills has also been acknowledged by some, such as the South African Wind Energy Association[27] and in the Just Energy Transition Investment Plan (JET-IP) 2023–2027[25].

In summary, the data drawn largely from macro-economic job projections show that the types of jobs emerging are largely technical, very focused on the transitioning energy technology within the formal sector and based largely on current models in which goods and services are produced and consumed. Not all studies are focusing equally on jobs related to enabling processes that support core energy-linked jobs (e.g. financing, procurement and regulation). Finally, the evidence shows that there are increasing emerging specialisations, which involves people moving into specialisations in existing jobs (rather than the creation of new jobs).

Supply context: Qualifications and provision

While the classification of over 230 courses identified as being offered by skills providers in the country has been slightly different for each study, in the main, they can be categorised into core energy (e.g. renewable energy, green hydrogen, energy efficiency and electric vehicles) and those supporting or enabling JET, such as social scientists, financial or legal specialists.

The research suggests that courses are offered across various skills provider types, with the majority of core-energy courses (41%) offered by private training providers and traditional universities (28%)[17,19,21] (see Figure 3).

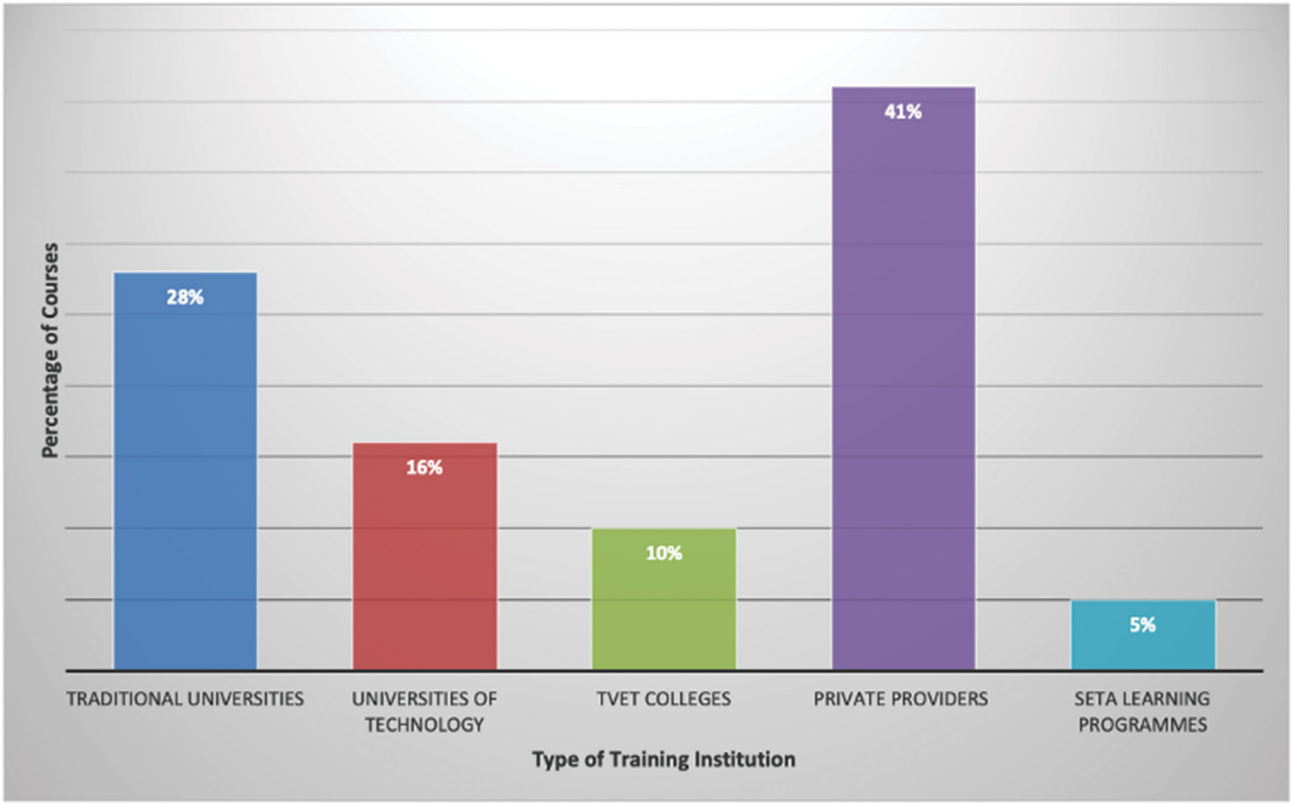


Figure 3: Percentage of core-energy courses offered across various institutions in South Africa.

Courses offered at universities tend to be informed by areas of focus of academic centres, for example, the Cape Peninsula University of Technology's South African Renewable Energy Technology Centre (SARETEC) and the University of Pretoria's Centre of New Energy Systems, which focuses on energy efficiency and demand side management. These centres tend to offer either specialist short courses or, in the case of traditional universities, postgraduate studies.[5,17,21]

Regarding Technical and Vocational Education and Training (TVET) college offerings, there is little evidence to indicate that renewable energy or energy efficiency is adequately covered. Those that are, tend to be doing so because of lecturer proactivity and interest in the field[17,21], or due to funding received to implement renewable energy programmes in partnership with, for example, Sector Education and Training Authorities (SETAs)[17,21]. This can result in an inefficient and unjust transition for individuals at entry and intermediate level. Morocco, which has reflected some success in JET, has showcased the need for involvement and collaboration of skills stakeholders from technical level to university level.[28] Further, McGrath and Powell[29], Papier[30] focusing on South Africa, and McGrath[31] focusing on India and South Africa, have supported the argument that VET institutions face challenges and have had minimal elements of green skills incorporation and sustainable development necessary for a just transition.

With reference to the course topics, this study found that most of the energy transition-related courses include various forms of engineering, science and/or technology education, biotechnology and biochemistry (see Figure 4). It is evident from the research that most courses offered target high- to intermediate-skills levels, with minimal focus on entry-level skills (such as for construction labourers for energy plants, machine operators or solar PV marketing assistants), and community learning.[5,18,21] This finding relates to the location of relevant skills provisioning, which indicates that while training may be provided in an area, it may not always be relevant to where demand is required. For example, the TVET college located in Upington in the Northern Cape, where there is a significant investment in solar PV, does not offer any certified renewable energy specific qualifications.[5]

Regarding the type of skills provisioning offered, the research suggests a propensity for short courses which are mainly offered by private providers (97%), relating to energy efficiency, management and auditing, and solar PV compliance, installation, financing and maintenance.[5,17,19,21] Universities are also responding to this demand, with at least 30% of their core energy courses offered as short courses.[5,17,19,21] It is evident that many of the short courses focus on a single job activity such as solar PV accreditation, as opposed to knowledge and skills required to fulfil the requirements of a job, such as a chemical scientist involved in green hydrogen. The research suggests this narrow focus can restrict career flexibility and progression, and vulnerability if jobs become obsolete.[5,21] While many of the short courses identified are certified, it was noted that many are not accredited and therefore not always of the quality or standard required of industry. Accreditation with bodies such as the South African Qualifications Authority (SAQA) is a lengthy process, and the urgency and high demand to provide courses means institutions are negating accreditation.[20,21] This short course culture has been highlighted as a disjointed sustainability response[32–34], suggesting a reactive, fragmented and poorly coordinated education and training landscape.

Lastly, many of the research interview respondents raised issues around the timely supply of skills and the oversupply of skills. For example, an estimated 1800 to 2200 wind construction jobs will be required each year up to 2030 if the country's Integrated Resource Plan[35] is to be realised[5,19,21]. Regarding oversupply, the research suggests that some graduates struggle to access the sector as job vacancies are limited due to the market not being ready to absorb the number of graduates being produced.[5]

So are we on track? What do the skills demand and supply data not tell us?

The findings above highlight some important insights that these studies are bringing to the fore, but in the discussion below, we try to illustrate some key issues that current approaches to researching skills are missing, all of which, we argue, are central to achieving a JET.

Across the work, from a skills perspective, there is strong evidence of an uncoordinated transition. While there are multiple studies, there is no coordination of the fragmented pieces of information. Despite the extensive and complex green/sustainable development mandate in policy, to date, no adequate coordination mechanism has been established for the national planning and development of JET skills in South Africa, which is leading to disparate and siloed skills interventions. For example, five separate studies on the hydrogen economy have been completed nationally by separate entities, focused on skills for TVET, SMMEs and manufacturing. From these studies, there is no clear indication of coordination; what emerges instead is a fragmented picture of pockets of demand with no national picture of skills demand to support the energy transition.[5,20]

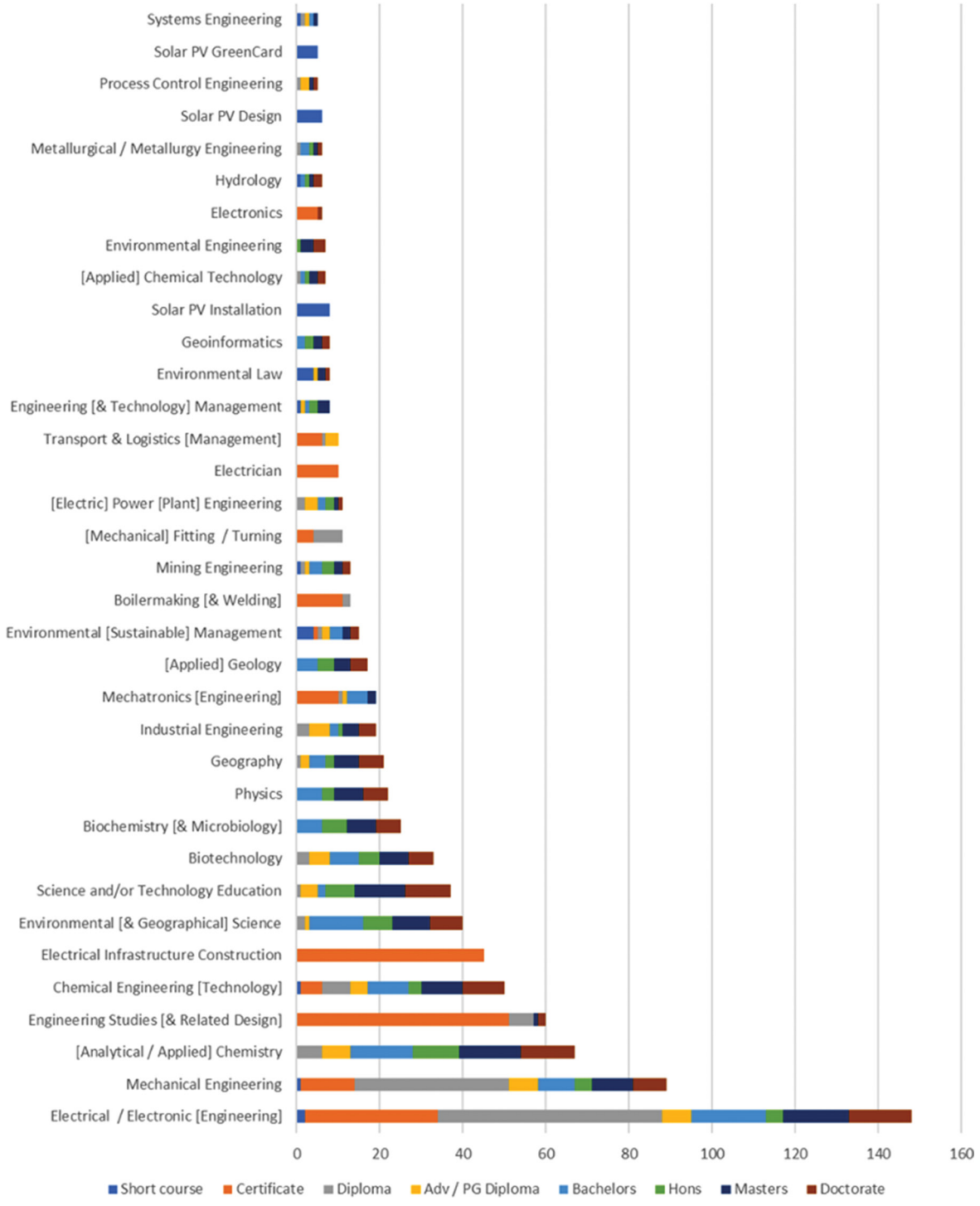
Many of the studies that have been undertaken are narrow in scope and focus on a sub-sector or technology. This reduces the transition to a technological transition and frames it within a market mindset. Furthermore, the data show the emphasis on technical jobs and for specific technologies. For example, energy efficiency was found to not receive as much attention as renewable energy. This casting of the transition as a technological one is driven with a focus on industry, building and preserving markets and inherently privileges industry. Further, it has been argued that countries like South Africa are overly reliant on energy-intensive industries and reflect patterns of mutual dependence among industry stakeholders and governments which can create a political 'lock-in' effect that is difficult to overcome.[26]

This fragmentation along technological lines perpetuates short-termism which constrains the futures perspective that a JET is aiming for. This is largely because much of the data come from employers and industry; thus, the longer-term picture is not clear from current demand data. Employer demand plays a key role in skills formation and anticipation. Although it must be used with caution, Allais[15] warns that employer needs data tend to provide limited insights into current and future skills demand trends. This approach does not provide a picture of the volatility of labour markets considering global shifts and trends, as has been noted, for example, by skills shifts in energy transitions due to climate change considerations.

With the current demand data for JET being speculative and short-termist, *ad-hoc*, fragmented and reactive, issues arise pertaining to the quality of education and training programmes delivered. The existing research outputs lack sufficient micro-level data and nuances necessary for informed educational planning. This includes the lack of detailed insights into the specific needs and challenges faced at the community and entry skills level. This deficiency limits the agility and responsiveness required to address evolving skill demands in the energy sector.[11] The reliance on speculative data and a lack of concrete insights makes it difficult to develop effective curricula and frameworks for teaching and learning processes as teaching and learning for JET demand the creation of situational conditions that reflect real-world challenges and opportunities.

Four critical issues emerge here. First, the supply-demand approach and the skills for jobs narrative inherent in the emerging findings all reflect an outlook of a neoliberal, market-led framing of the transition. This framing reduces the transformative impact needed for JET. Second, this clearly shows that with the market-led approach to skills, the sustainability ethic is being neglected, and we are not focused on disrupting the economic *status quo*. Third, the market-led analysis negates the critical role of communities as active participants in the transition, and fourth, a skill formation system that is trapped in colonial path dependency.

Consultations across these research projects have raised concerns that there are no clear existing learning pathways from the pre-tertiary to tertiary education and work-based learning. Within this context, learning pathways at entry-level into community colleges and adult learning centres are under-researched and restrict transitions into intermediate skills pathways. While TVET institutions emerge as vital conduits for equipping learners with specialised skills essential for advancing socio-economic development in a just and equitable manner, clear pathways



Source: South African National Energy Association[5] (reproduced with permission)

Figure 4: Just energy-related courses identified in 2022 with more than five offerings across the South African post-school education and training system, by qualification level.

into and from TVET are not visible. Clear learning pathways represent critical trajectories guiding individuals through educational endeavours to acquire knowledge and skills for a sustainable energy future.[36] However, the projects reveal that numerous challenges impede the effectiveness of these pathways for youth entrants. These include inadequate infrastructure, limited access to quality education for marginalised and rural communities, a skills mismatch where curricula offered by TVET institutions often fail to align with the evolving needs of the local energy sector, as well as maladjusted skills system issues.[36,37] Furthermore, the issues raised around unaccredited training and training that does not meet industry standards place further constraints on pathways. Lastly, the skill reform system remains skewed by the apartheid growth model and skill development strategies linked to massive industrialisation and the Mineral Energy Complex (MEC).[38] Under this model, the colonised population was mostly restricted to basic education and VET education, which were considered sub-par to general education.[39] This then led to entrenched poverty and inequality, which persists as the belief system[31] and continues to impact education and career pathways.

As shown above, the directionality of the energy transition has left poverty and inequality intact. It has cast itself in a neoliberal paradigm and structured itself to recreate the existing labour market. So, it is our

contention that unless a JET adopts a more radical/disruptive whole system approach, rather than the fragmented approach that is currently evident, we are on the path to an unjust energy transition.

Conclusion

Despite increasing awareness of the need for a JET, the directionality of current efforts has failed to address persistent poverty and inequality, indicating a deviation from the path towards a truly equitable future. This disconnect between rhetoric and reality underscores the urgency for a fundamental reassessment of the approach to skills development within the context of broader societal transformations. Fragmentation and disjointed efforts characterise the landscape, hindering the effective alignment of skills with emerging demands and societal needs, hence undermining the efficiency of skills development but also perpetuating disparities, leaving marginalised communities further behind. When reflecting on skills for JET, it becomes evident that incremental adjustments are insufficient to address the magnitude of the challenges ahead. Instead, a more radical and disruptive whole-system approach that looks beyond supply and demand statistics is imperative. This entails reimagining the role of institutions, fostering collaboration across sectors, and prioritising the voices of those most affected by transition processes.

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Data availability

The data supporting the results of this study are available upon request to the corresponding author.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. Ethical considerations were maintained throughout the data collection process. This was done by obtaining informed consent from participants, ensuring anonymity and confidentiality in the interviews and the reporting. Ethical clearance certificates were obtained from the Human Research Ethics Committee (Non-Medical) at the University of the Witwatersrand with the following protocol numbers: H23/08/27 and H20/03/22. Drawing on this empirical work, this paper offers a meta-reflective 'landscape view' of the JET skills field as it is emerging.

Authors' contributions

P.R.: Conceptualisation; methodology; data collection; data analysis; validation; data curation; writing – the initial draft; writing – revisions; student supervision; project leadership; project management; funding acquisition. V.H.: Conceptualisation; methodology; data collection; data analysis; validation; data curation; writing – the initial draft; writing – revisions. W.I.J.P: Conceptualisation; methodology; data collection; data analysis; validation; data curation; writing – the initial draft; project leadership; project management; funding acquisition. N.J: Conceptualisation; methodology; data collection; data analysis; validation; data curation; writing – the initial draft; project leadership; project management. All authors read and approved the final manuscript.

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