Transforming sustainability education through transdisciplinary practice

Keywords

Transformative learning; transdisciplinary; urban; reflexivity; complexity

Abstract

Addressing urban sustainability challenges through transformative learning requires learners to be receptive to alternative viewpoints and to critically analyse their own assumptions and worldviews. Higher education institutions have an important role to play in addressing such challenges through their capacity to bring together diverse stakeholders and implement structured learning activities that can enable transformation on a personal and societal level. This article presents a case study of how urban sustainability has been incorporated into various courses run by the TD (transdisciplinary) School at the University of Technology Sydney. The findings illustrate that a transdisciplinary approach to higher education can facilitate transformative learning through a focus on real-world challenges, complex systems thinking, the integration of diverse knowledges and reflexivity. The lessons emerging from the case study demonstrate the importance of both enabling students to obtain a transdisciplinary skillset through their education and ensuring that educators adopt a transdisciplinary mindset to curriculum design.

Introduction

With more than half of the world's people already living in cities, urban expansion is projected to account for almost all future population growth to 2050 (United Nations 2019). Goal 11 of the UN Sustainable Development Goals (SDGs) aims to "Make cities and human settlements inclusive, safe, resilient and sustainable", but the fact that we now live in a mostly urban world means that urban sustainability is central to the achievement of the other 16 SDGs as well, including those relating to poverty, work, education, sanitation, resource consumption, energy and climate change. Achieving these goals in the context of expanding urban populations and "already strained resources" (United Nations 2019) will require transitions away from current ways of living in cities to unknown and contested futures. The enormity of this task requires transdisciplinary approaches that are able to harness a broad diversity of knowledge types to address the challenges we face, as well as transformative learning that enables urban stakeholders to identify possibilities that can only emerge from new ways of seeing and thinking about these challenges.

Transdisciplinary approaches to urban sustainability offer the potential to integrate knowledge from diverse domains, recognise real-world complexity and engage affected stakeholders in processes of mutual learning (Klein 2017). Higher education institutions, which are predominantly located in urban areas, can facilitate transdisciplinary approaches to urban sustainability by exposing students to real-world challenges and diverse perspectives, and by enabling students to apply transdisciplinary principles to the challenges they encounter. Preparing students to be transdisciplinary practitioners requires a challenge-led approach to teaching and an exposure to a breadth of knowledge types. It also requires that students are equipped with a toolkit they can employ to integrate and translate the diverse knowledges they will encounter in their future work and to engage in processes of reflexivity

that require them to scrutinise the choices that are made when identifying and integrating diverse knowledges, values and worldviews (Polk 2015).

Transformative learning involves the transformation of one's beliefs about themselves and the world around them through critical assessment of received assumptions and underlying premises (Mezirow 1991). This may be facilitated by exposure to alternative viewpoints and experiences, in conjunction with "consciously directed processes" that enable the critical analysis and reflection required to transform one's own assumptions and worldviews (Elias 1997). Transdisciplinary approaches are well-suited to enabling transformative learning in higher education (Leal Filho et al. 2018), especially through a focus on exposing students to a diverse range of knowledges and perspectives, and a focus on reflexivity, which enables students to unpack the roles played by values, norms and worldviews in defining, framing and addressing sustainability issues. However, there is a gap in knowledge around how transdisciplinary learning experiences can be designed to maximise opportunities for transformative learning.

This article addresses the knowledge gap around designing transdisciplinary learning for student transformation by exploring how some of the key principles underpinning a transdisciplinary learning approach have been employed in subjects that the author has coordinated or helped to develop at the University of Technology Sydney, Australia, since 2017. The key question guiding this case study exploration is "how can the inclusion of transformative learning in prevailing higher education systems be enabled through the adoption of transdisciplinary approaches". Consideration is also given to the role that has been played by the COVID-19 pandemic in forcing the development of new approaches and helping to illuminate new possibilities around transdisciplinary learning and teaching.

Background to transdisciplinarity, transformative learning and urban sustainability

Since the term "transdisciplinary" appeared in the 1970s, various meanings and applications of transdisciplinary principles have evolved. Klein (2017) identifies a number of key principles common to different definitions, including the integration and transcendence of academic disciplines, the participation of diverse stakeholders, a focus on "real-world" problems, a recognition of complexity and the need for explicit processes of reflexivity to enable mutual learning and knowledge integration. Scholz and Steiner (2015) describe this approach as "Mode 2" transdisciplinarity to distinguish it from the earlier "Mode 1" approach advocated by Piaget (1972), which was focused primarily on achieving a "unity of knowledge" and lacked a strong societal or functional dimension. Scholz and Steiner (2015) contend that the environmental challenges of the 1980s played a critical role in the development of Mode 2 transdisciplinarity and this nexus between sustainability and transdisciplinarity remains prominent in research undertaken since that time (e.g. Polk and Knutsson 2008; Evans 2015; Fam et al. 2017; Petra and Christian 2017).

The integration of different knowledges and epistemologies that is central to transdisciplinary learning requires both a willingness and an ability on the part of participants to respect, understand and adopt new forms of knowledge. Transdisciplinary approaches also require consideration of knowledge beyond that which is clearly disciplinary or academic. Conscious efforts must be made to include practice-based, local and Indigenous knowledges, and to recognise that "people living or acting with a system on an extended or even daily base are considered the case or system experts" (Scholz and Steiner 2015). Participants in

transdisciplinary processes should be embedded in the context of enquiry, not just as informants or stakeholders, but as equal partners, with the distance between researchers and the subjects of research diminished to generate mutual learning amongst all involved (Polk and Knutsson 2008).

In relation to urban sustainability, Polk (2015) discusses a range of participatory methods that have been employed under the transdisciplinary co-production framework developed at Mistra Urban Futures in Sweden (Table 1). Their participatory approach explicitly considers both inclusion and collaboration, recognising that a diverse range of stakeholders need to be involved in the production of knowledge and that specific collaborative processes and methods are required to produce high-quality contributions. In the context of higher education, a key challenge is to transcend traditional dichotomies such as "teacher-student" or "expert-novice" to embrace a broader group of participants, including industry partners and local community members, each with knowledge to offer and learning to be achieved (Baumber et al. 2020). The creation of "third spaces", both physically and metaphorically, can be effective in breaking down such boundaries to enable mutual learning (Kligyte et al. 2019).

Table 1: Methods reported by Polk (2015) across five urban planning case studies

Data collection methods	**Transdisciplinary co-production methods**
• Focus groups • Seminars • Public and design workshops • State of play mapping • Network development • Student projects and trials • Interventions	• Co-leadership • Joint data collection • Co-authorship of scientific papers and policy reports • Democratic meeting methods • Open participation in large project group • Professional working groups

Schneider et al. (2019) present an alternative framework for transdisciplinary co-production that differs from Polk's in that it focuses more heavily on impacts and transformation pathways (Figure 1). Under this model, the generation of new knowledge is not the ultimate purpose of transdisciplinary co-production, but rather one of three primary outputs, along with the creation of shared understandings and new competencies. In turn, these three outputs are aimed at informing decision-making, supporting collective action and promoting reflective leadership in order to achieve transformational change in the direction of sustainability.

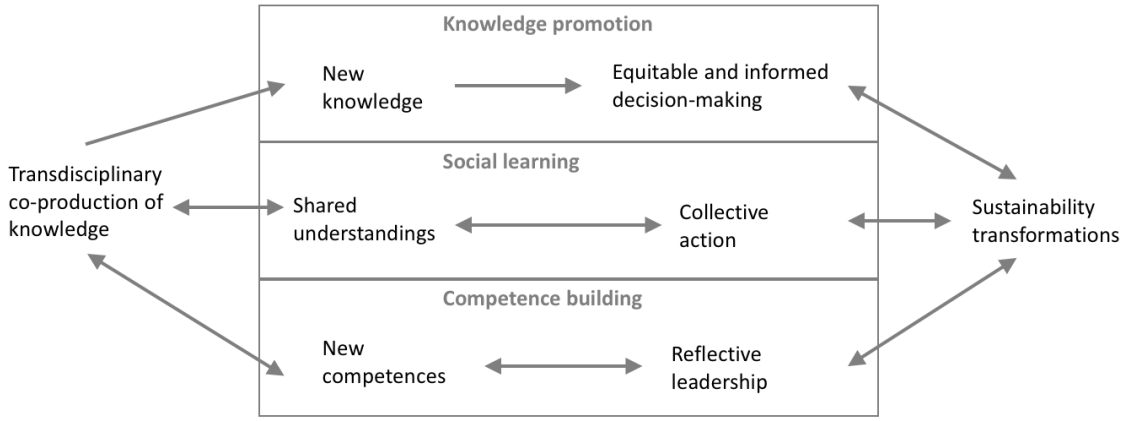


Figure 1: Generic mechanisms for impact from transdisciplinary co-production. Re-drawn from Schneider et al. (2019). Arrows indicate the direction of influence.

The focus on decision-making and transformations in Figure 1 highlights the "action-oriented" approach to societal problem-solving that is central to transdisciplinary practice. Burger and Kamber (2003) contend that it is this focus on action, along with the participation of non-scientific stakeholders, that sets transdisciplinarity apart from interdisciplinarity. The term "real-world" is often used as a qualifier to indicate that the problems being addressed are "exogenous", or sourced from the broader community, rather than simply being of interest within universities (Klein 2017). This real-world focus is also central to transformative learning, with Wanner et al. (2020 p. 23) arguing that learners must develop a "a changed relationship to the world" and Schneidewind et al. (2016) advocating for the creation of "real-world labs" to explore societal challenges. In relation to university teaching on urban sustainability, this approach requires universities to bring urban stakeholders and their challenges into the learning environment, as exemplified by the "Sustainability Challenge" course offered jointly by four Austrian universities since 2010 to identify "real answers to urban sustainability challenges" in Vienna through transdisciplinary practice (Petra and Christian 2017 p. 63).

The focus of transdisciplinary practice on the real world rather than on theory or controlled settings also requires a recognition of complexity and a rejection of reductionism. This focus on complexity includes a recognition of pervasive uncertainty (Popa et al. 2015), the non-linearity of many relationships within socio-ecological systems (Polk and Knutsson 2008) and the "multi-layeredness of tradeoffs and conflicts" when multiple stakeholders are engaged in decision-making (Scholz and Steiner 2015 p. 528). In the context of transdisciplinary higher education, equipping students with the ability to view complex challenges through a systems lens can be a key enabler of transdisciplinary practice, allowing them to operate in conditions of high uncertainty and to approach challenges in a manner that is experimental, iterative and adaptable to different contexts (Jantsch 1972; Max-Neef 2005).

While complex systems thinking has been central to the development of transdisciplinary approaches to research and learning, Popa et al. (2015) caution that this can at times lead to a focus on describing and analysing systems (e.g. by co-creating knowledge or building models with diverse stakeholders) at the expense of genuine system transformation. They argue that transformational approaches require an interconnection between understanding knowledge and using it to achieve change. Such transformational approaches are particularly relevant for sustainability-related challenges like climate change, which require strategies aimed at transcendence and creating previously unimagined possibilities rather than incremental

approaches focused on replication and performance improvement (Fazey et al. 2018). This need for transformational change to deliver sustainable futures in turn creates a need for transformative learning, which requires higher education institutions to "operate as knowledge and reflection institutions developing critical thinking and not only as teaching institutions that transfer knowledge" (Leal Filho et al. 2018 p. 287). Amongst scholars of both transdisciplinarity and transformative learning, the term reflexivity is commonly applied to the processes of critical thinking that are required to integrate diverse knowledges and perspectives.

Reflexivity is a key element of transdisciplinary practice that enables the integration of knowledge amongst diverse participants through the "on-going scrutiny of the choices that are made when identifying and integrating diverse values, priorities, worldviews, expertise and knowledge" (Polk 2015 p. 114). Indeed, Jahn et al. (2012 p. 2) contends that this focus on reflexivity is "both the claim and the main purpose" of transdisciplinary practice. Similarly, Wanner et al. (2020 p. 23) describe reflexivity as the "overarching goal" of transformative learning, which can be achieved by "encouraging critical thinking or the adoption of a critical perspective on current societal developments". Polk and Knutsson (2008) also highlight that reflexivity is essential for "mutual learning" around sustainability challenges.

While reflexivity is a core component of both transdisciplinarity and transformative learning, Popa et al. (2015) argue that it is often applied in a limited manner and requires more careful consideration at all stages of transdisciplinary enquiry. Enhancing reflexivity requires participants in transdisciplinary projects to engage with difference and to question underlying assumptions and value-subjective conceptualisations and framings of complex challenges (Klein 2017). Specific practices for enhancing reflexivity include "intervention research" aimed at initiating individual reflection through research (Schneidewind et al. 2016), "reframing" a challenge from a different perspective (Dorst 2015) and "double-loop learning", which goes beyond increasing the efficiency of agreed upon rules, strategies and norms (single loop learning) to engage in a critically reflexive process of whereby the assumptions and values underlying existing rules, strategies and norms are re-evaluated (Polk and Knutsson 2008).

Case study: Transdisciplinary learning at the University of Technology Sydney

Case study methodology

The case study focuses on sustainability-related subjects across three undergraduate coursework programs delivered by TD School (i.e. Transdisciplinary School) at the University of Technology Sydney (UTS). Sustainability is a core focus for UTS, with one of the five values underpinning the UTS 2027 Strategy being "Sustain our local and global environment, organisational health and our ability to create a positive, viable future". This core value feeds into current teaching-related initiatives around lifetime learning, personalised leaning, partnerships and social change, as well as guiding UTS' research agenda (UTS 2021).

The three programs that are the focus of this case study are the Bachelor of Creative Intelligence and Innovation (BCII), the Bachelor of Technology and Innovation (BTi) and the Diploma in Innovation (DipInn). The BCII commenced in 2014 and follows a double-degree

model that allows students to choose from 25 different "core degree" options delivered by other faculties (e.g. business, design, communications, science) while coming together periodically for intensive transdisciplinary subjects every six months and then spend their entire fourth year undertaking transdisciplinary subjects full-time. DipInn students also undertake transdisciplinary subjects alongside their core degrees, but without the full-time final year that the BCII involves. In contrast, the BTi was designed to follow a single-degree 3-year model where most subjects are transdisciplinary and students undertake a smaller set of disciplinary-oriented subjects as electives.

The BCII, BTi and DipInn all involve subjects with an urban sustainability focus. The BTi and DipInn have dedicated subjects on sustainability, while the BCII allows students to choose sustainability-related challenges for 3-month projects in their final year. All three courses incorporate a focus on real-world issues by bringing in industry partners to set challenges for students and involve teaching staff from a diverse range of disciplinary backgrounds, including science, social science, engineering, design, policy studies, business, creative arts, health and education. The BCII is the largest of these three programs in terms of student numbers, with over 400 students enrolled in 1st year and up to 130 students undertaking the 4th year subjects that allow students to undertake sustainability challenges (compared to class sizes of 10-30 for the BTi and DipInn sustainability subjects).

The following four sub-sections explore how the following key principles of transdisciplinary practice have been implemented in learning activities on urban sustainability in TD School: real-world challenges; complexity; integration of diverse knowledges; and reflexivity. The aim of the case study is to identify lessons around how transformative learning can be achieved in transdisciplinary higher education. The sources of information used to determine whether transformative learning has taken place include student feedback, partner feedback and external recognition of transformative learning. The aim of this case study does not extend to the direct measurement of environmental or social outcomes for partners, such as a reduction in greenhouse gas emissions, due to the long timeframes that are often involved in converting learning and mindset transformation into action and measurable outcomes.

Real world challenges

UTS is the most centrally-located of all of Sydney's major university campuses, being less than 500m from Central Railway Station and tightly integrated with surrounding offices and retail outlets. As such, the challenges that partners set for students to work on are often urban in nature. Partners include developers involved in major urban development projects, government agencies who are grappling with some of Sydney's most pressing sustainability challenges, and businesses who are dependent on the flows of people, resources and knowledge that cities facilitate.

A sample of recent urban sustainability challenges presented to 4th year BCII students are shown in Table 2, drawn from a cross-section of corporate, government and not-for-profit partners. These partner challenges were undertaken by students in the first half of the 4th year program in 2020, with students then able to develop their own "passion" projects in the second half of the year. Urban sustainability topics are also prominent amongst these passion projects, including construction of sustainable homes using waste materials, connecting urban residents with nature in their local neighbourhoods and creating local food-sharing networks to reduce food waste.

Table 2: Urban sustainability challenges posed by partners to 4th year BCII students in 2020

Complex challenge	Partner type
Delivering better medium-density housing, more efficiently and cost-effectively, to meet a growing demand for affordable housing	Property developer
Creating an economically competitive urban farming system that is holistic and inclusive of social and environmental concerns, and inclusive of Indigenous knowledge.	Government planning and development agency
Re-imagine and determine a vision for the role buses will play in the future of Australia's transport ecosystem.	Corporate sector consultancy
How can we better engage with our social housing tenants and communities to facilitate change, build trust, increase community cohesion and address social issues they are facing?	Not-for-profit social housing provider

Student feedback surveys routinely cite exposure to real-world challenges and partnerships as a strength of TD School's courses and incorporation of student and partner feedback has helped to improve the overall feedback scores over time. For the subject in which the challenges in Table 2 take place, the average level of agreement amongst students that "Overall, I am satisfied with the quality of this subject" has progressively increased from 3.88 (out of 5) in 2017 to 4.07 in 2018, 4.17 in 2019 and 4.47 in 2020 (i.e. halfway between "agree" and "strongly agree"). Further recognition for the BCII was also provided in the form of national awards for partnership-building from the Australian Awards for University Teaching (AAUT) in 2020 and for industry problem-solving from the Business Higher Education Round Table (BHERT) in 2019.

One of the areas in which learning has taken place amongst TD School staff is around how best to procure and position industry challenges within transdisciplinary courses. Much of this learning has been undertaken in partnership with students, who have engaged collaboratively with staff in curriculum co-creation and co-revision (Baumber et al. 2020). One key learning that has been gained in the BCII's 4th year program is the need for students to feel that the challenges presented by partners are "real" and that the responses students develop have a genuine chance of being valued and potentially implemented in some form by the partner organisation. Students have also expressed desires for a diversity of challenges, with the industry partnerships team taking particular effort to ensure that there are several challenges with a sustainability or social justice dimension each year. The value of having a dedicated industry partnerships team to source partners and challenges is also difficult to overstate, as this involves a considerable workload that is additional to the usual responsibilities of academic staff in designing and running learning activities for the subjects they coordinate. Bringing the "real world" into a classroom environment is essential to transdisciplinary education, but requires a considerable commitment of resources to make it happen.

In 4th year BCII, industry partners are given guidance around how to present their challenges. Partners are encouraged to provide detailed and specific advice on the challenges they are facing, while remaining open to a range of potential responses that students might come up

with. This careful guidance is important for enabling learning that is both transdisciplinary and transformative, as students are encouraged to bring their own different perspectives to the challenge and to "reframe" the challenge in ways that question its underlying assumptions and premises (these elements are discussed further below in the sections on integrating knowledges and reflexivity). Encouraging students to critically analyse their challenge briefs in this manner requires a nuanced relationship between partners and students that transcends simple dichotomies like expert-novice, supervisor-intern, teacher-student or client-consultant and works towards the kind of mutual learning advocated by Polk and Knutsson (2008). However, achieving such relationships requires careful communication, expectation management and adaptability, as partners, students and teaching staff are often inexperienced at working in this manner.

Complexity

Aside from ensuring that challenges are "exogenous", or sourced from the "real world" (Klein 2017), a transdisciplinary approach also requires that students have the skills and methods they need to unpack the complexity of the real-world contexts they are investigating. Within the BTi and DipInn programs, students study a dedicated subject covering complexity and sustainability, while in the BCII a dedicated complexity subject is covered in the year prior to undertaking the major 4th-year projects. Key concepts covered in these complexity subjects include systems mapping, causal loops, resilience principles and intervention strategies for complex adaptive systems.

While working on real-world challenges set by industry partners, TD School students map out the various stakeholders and elements within the system using simple system maps, influence diagrams, causal loops, rich pictures, agent-based modelling and stocks and flows models. Resilience concepts are explored through the use of the "basins of attraction" model (Figure 2), in which system states are envisioned as basins between which a "ball" (the current condition of the system) may move (Walker et al. 2004). The current system condition may shift in response to system disturbances, but is also affected by balancing feedbacks, which help to keep it in its current state, and reinforcing feedbacks, which can exacerbate shifts to an alternate state.

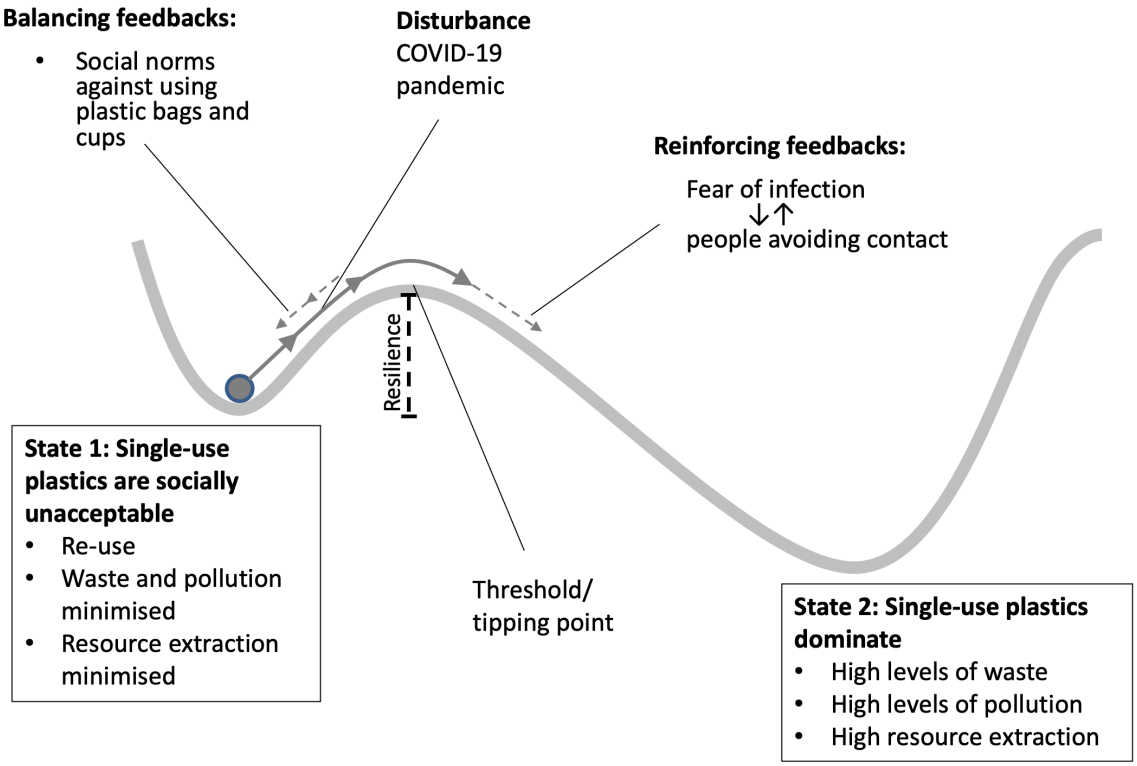


Figure 2: Example of the basin of attraction model used in class to explore shifting behaviours around single-use plastics in Sydney during the COVID-19 pandemic

The COVID-19 pandemic presented an opportunity to explore how a major disturbance might affect a complex system in real time, including through the urban sustainability example shown in Figure 2. In the first half of 2020, it became noticeable in Sydney that concerns about the spread of COVID-19 had led to cafés no longer accepting reusable coffee cups. This was something that many students could relate to as a personal experience of urban sustainability, as reusable coffee cups had become widespread in the period prior to the pandemic, along with reusable shopping bags and other measures to reduce the use of single-use plastics. Whilst the pandemic presented many uncertainties, it was easy for students to conceive of a future in which concerns about physical contact compounded to the point where reusable plastics became socially unacceptable (i.e. a reinforcing feedback), as well as a future where pre-existing social pressures to avoid single-use plastics reasserted themselves and led to return to the reusable coffee cup culture in Sydney (i.e. a balancing feedback). The use of simple, relatable examples like this has always been a feature of TD School courses, but the pandemic offered an opportunity to demonstrate how complex adaptive systems respond to a major system disturbance in real time.

Aside from mapping and analysing elements of complexity within complex adaptive systems, the complexity subjects in the BCII, BTi and DipInn also have a focus on intervention strategies. Students are encouraged to design interventions for the complex challenges they are investigating by applying strategies such as adaptive management (Stankey et al. 2005) and safe-to-fail experiments (Ahern 2011) that have been developed to deal with pervasive uncertainty in complex socio-ecological systems. Students also identify places to intervene using the 12 leverage points developed by Meadows (2008) and the enabling factors for

general resilience identified by Carpenter et al. (2012). Students are given examples of how these resilience factors have been applied and adapted to urban resilience (Suárez et al. 2020), including in relation to the COVID-19 pandemic (Table 3). The pandemic provided an opportunity to identify and discuss sources of resilience in different urban contexts before and after the arrival of the pandemic. The exercise shown in Table 3 was also used to identify potential strategies for enhancing the factors discussed, including diversity, self-organisation and social capital.

Table 3: Results of a class exercise used to illustrate how enabling factors for resilience may vary in different urban contexts. Factors are adapted from Carpenter et al. (2012) and Suárez et al. (2020).

Enabling factor for general resilience (pre-pandemic)	**Resilience ratings assigned to hypothetical businesses operating in different parts of Sydney pre-pandemic**		
	Small business in central Sydney	**Small business in outer suburbs**	**Justification for ratings**
Reserves or buffers: e.g. cash, insurance, borrowing capacity, other resources, skills)	8/10	6/10	Foot traffic in city creates higher turnover but there are also higher fixed costs
Diversity: A mix of strategies and stakeholders so system can pivot in different directions	6/10	8/10	Businesses in central city are highly dependent on a single customer type (office workers)
Self-organisation: Autonomous, loosely-connected parts of system that can adapt quickly (modularity)	6/10	8/10	Local businesses have a more reliable customer base that they can focus on, especially when people decide to travel less and shop locally
Connections to neighbouring systems and higher levels: e.g. friends, national government, global responses	9/10	6/10	The central city is a much denser and more complex system of co-existing actors and organisations
Information flows and feedbacks: Enable rapid, informed and adaptive responses	5/10	8/10	Local businesses are better connected to their local communities
Social capital: Leadership, trust and cooperation	6/10	8/10	Local businesses have higher levels of trust, loyalty and psychological co-ownership

OVERALL RESILIENCE SCORE	67%	73%	

Integration of diverse knowledges

The inclusion of diverse knowledges and perspectives is integral to transdisciplinary learning (Klein 2017). In the context of higher education, exposure to knowledge from different disciplines or faculties across a university is one obvious way to enhance knowledge diversity. This is particularly pronounced in the BCII, where students from 25 different core degrees across eight faculties are sorted into multi-disciplinary teams of between four and six students to collaborate on real-world challenges. In addition to each student being encouraged to apply their own disciplinary expertise to a challenge, teaching staff are drawn from multiple disciplinary backgrounds and class activities commonly focus on how an issue might be approached within different disciplines. One example from 4th year BCII is a class on experimentation, where academics discuss the principles of experimentation that they commonly apply in their specific disciplines, including forensic science (randomisation and replication), design (iteration and co-creation), creative arts (provocation and boundary-testing) and environmental management (adaptive management experiments).

Transdisciplinary approaches require that participants go beyond disciplinary or academic knowledge to also consider practice-based, local and Indigenous knowledges (Scholz and Steiner 2015). The inclusion of industry partners in setting student challenges provides an important source of practical and contextual knowledge in TD School, but students are also challenged to consider other knowledges and perspectives that may be absent. This requires consideration of demographic factors such as age, gender, ethnicity, disability and religion, emphasising Elias' argument that transformative learning requires a combination of self-awareness, critical reflection and learning structures that enable equal access to information exchange (Elias 1997).

One class exercise aimed at expanding students' exposure to diverse knowledges involved a guest lecturer from the UTS Centre for Advancement of Indigenous Knowledges (CAIK) discussing Aboriginal approaches to sustainability in the Sydney Basin prior to European colonisation. This session had a focus on the interconnections between spirituality and natural resource management, and the importance of shared beliefs, norms and rules guiding maximum take levels or seasonal limits on accessing resources and prohibitions on particular community members harvesting certain plant and animals (e.g. based on gender or totems). The value of this session was apparent the following week, when the students played the "Fishbanks" game developed by MIT Sloan to explore sustainability issues that can arise in open-access resource systems. When asked to suggest possible solutions to the overharvesting of fish that occurred in the game, students initially suggested measures such as real-time population monitoring, restrictive licensing and tradeable quotas, illustrating common Western biases towards managing complex systems through formal regulations, market-based mechanisms and a quest for scientific certainty. When reminded of the previous week's exercise, students began to suggest ways in which informal rules, shared beliefs, customs and norms could also be employed to address unsustainable resource use.

Reflexivity

TD School courses include numerous activities in which students are required to practice reflexivity by scrutinising the choices that they and other stakeholders make when determining which knowledges, expertise, values and worldviews are prioritised in setting and addressing complex challenges (Polk 2015). Aside from being encouraged to identify and seek out knowledges and worldviews that may be absent from their project teams, students are also guided through specific exercises on reframing, double-loop learning and unpacking their own pre-existing worldviews and paradigms.

In 4th year BCII, students are asked to "reframe" the challenge briefs they have been given by industry partners using the "frame creation" approach developed by Kees Dorst (Dorst 2015). This approach is designed to generate new ways of thinking about the problem situation surrounding a complex challenge by asking "*If* the problem situation is approached *as if* it is a problem of …, *then*…". The aim is not to identify a single correct framing or a single correct "solution", but rather to generate new possibilities by viewing the problem situation from different angles. Students are encouraged to use metaphors to imagine possible futures and to unpack the assumptions and underlying premises within dominant industry practices. Returning to the sample challenges shown in Table 2, student teams were able to reframe:

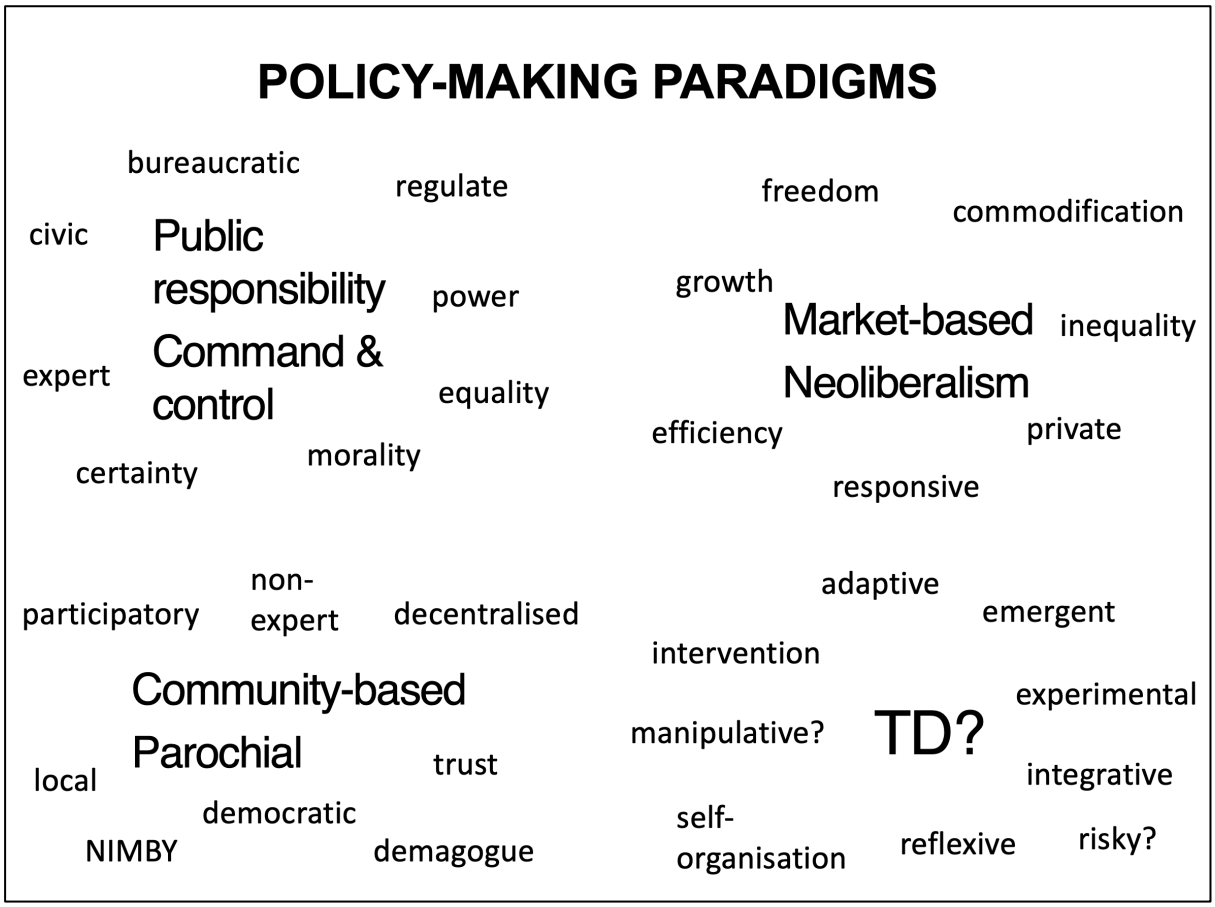
- The housing affordability challenge from a focus on affordability for home-buyers to a question of whether we as a society can "afford" to waste resources through inefficient building practices that generate construction wastes;
- The urban farming challenge from "creating" an urban farming system to "facilitating the conditions" for innovation in urban agriculture, linked to the notion of guided self-organisation (Prokopenko 2014);
- The bus challenge from a focus on what buses might do in the future towards future needs for "accessible transportation" (and whether buses could play a role in meeting these needs); and
- The goals of the social housing project (facilitating change, building trust and increasing cohesion) to a broader framework for building long-term community resilience.

As noted previously, careful management of expectations is crucial for facilitating the type of reframing that students undertake in TD School courses. Challenging underlying assumptions, seeking different perspectives and presenting alternate frames is not necessarily common in traditional teacher-student, expert-novice or client-consultant relationships. As such, industry partners require careful guidance on the processes that students will be undertaking and students require guidance on how to manage these conversations with partners. One approach used to assist students in having these conversations is double-loop learning, whereby students are asked to assess not only how effectively certain actions may be achieving current goals, but also what assumptions, values and norms underpin those goals (Polk and Knutsson 2008) and whether new goals are required. By having these conversations in an ongoing manner with industry partners, prior assumptions may be challenged and new goals established through a process of mutual learning. This also prevents reframing coming as a sudden or unwanted shock to partners. Attempts have been made to frame this collaborative environment as a shared "third space" that does not belong exclusively to partners, students or teaching staff and in which these roles and relationships can be reimagined (Kligyte et al. 2019).

One example of a reflexivity exercise that has been employed to unpack students' own underlying assumptions and premises is the "policy paradigms" exercise in 4th year BCII (Figure 3). Students are exposed to three different types of policy mechanisms that could be used to address sustainability issues, with Australia's fossil-fuel-dependent energy system given as an example. The three policy types are each introduced using two possible names, one with a positive connotation and one with a negative connotation – i.e. "public responsibility" vs "command and control", "market-based" vs "neo-liberal", and "community" vs "parochial". Similarly, the descriptions used for each paradigm include terms likely to be seen as positive (e.g. freedom) and as negative (e.g. inequality) by students in an Australian university. Students are then asked to place a sticky note on a Venn diagram indicating their own underlying assumptions about which of the policy paradigms are likely to be effective for addressing sustainability issues, followed by a discussion of why they feel this way.

The final step in the policy paradigms activity is to challenge students to come up with terms that might describe a transdisciplinary (TD) policy paradigm, including terms that potentially could have negative connotations for some stakeholders, such as "risky" (due to an experimental mindset) and "manipulative" (e.g. designing interventions for complex systems). Through this exercise, students are encouraged to critically analyse their own underlying biases and assumptions, as well as to critically analyse the transdisciplinary principles they have been taught about for the past four years, rather than simply "drinking the TD Kool-Aid".

Figure 3: Terms used to describe different policy paradigms in a class exercise



Discussion

Table 4 summarises the key lessons identified through the case study in terms of achieving transformative learning through the incorporation of transdisciplinary principles around real-world challenges, complexity, integration of diverse knowledges and reflexivity. The evidence that transformative learning has taken place through the application of these principles and lessons include student feedback (which has improved progressively over time), external recognition (e.g. AAUT and BHERT awards) and supporting statements provided by industry partners for these award nominations, which emphasised the role played by BCII students in helping them to identify fresh thinking, creative solutions and breaking down "silos" of knowledge. The insights in Table 2 build upon a growing body of knowledge about transdisciplinarity, transformative learning and urban sustainability in higher education, including the "Sustainability Challenge" course run by four Austrian universities (Petra and Christian 2017), comparative studies across Europe, Africa, Asia and South America (Leal Filho et al. 2018) and US, Swedish and German sustainability programs reviewed for the Transformative Innovation Lab project in Germany (Wanner et al. 2020).

Table 4: Lessons learnt around achieving transformative learning in transdisciplinary higher education

Transdisciplinary principle	**Lesson learnt**
Addressing real-world challenges	• Ensure students feel that their challenges are "real" and their work could lead to future action • Ensure that students are exposed to a diversity of challenges and partner types • Guide partners to ensure that they are open to a range of potential responses to their challenges and can help students understand the challenge deeply and from multiple perspectives
Complexity	• Provide students with a toolkit to unpack the complexity of real-world challenges they encounter • Take advantage of opportunities to bring real-world developments into learning in real time (e.g. Covid-19 pandemic experiences) • Frame student responses to challenges as interventions in complex systems rather than "solutions"
Integration of diverse knowledges	• Bring students from diverse academic backgrounds together to work on challenges • Include teaching staff from diverse academic backgrounds • Go beyond "disciplinary" or "academic" knowledge to include local, practice-based and Indigenous knowledges and lived experience • Consider factors such as age, gender, ethnicity, disability and religion when designing for diversity • Include students and external partners in processes of curriculum co-creation

Reflexivity	• Break down traditional relationship dichotomies such as teacher-student, supervisor-intern and client-consultant • Create third spaces for mutual learning that do not belong soley to either students, staff or partners • Allow space for students to reframe challenges set by partners and ensure partners are open to this • Guide students in applying reflexivity through methods such as frame creation and double-loop learning

Reflexivity is arguably the clearest area of overlap between transdisciplinarity and transformative learning, with Jahn et al. (2012 p. 2) contending that reflexivity is "both the claim and the main purpose" of transdisciplinary practice and Wanner et al. (2020) describing it as the "overarching goal" of transformative learning. Structured approaches to reflexivity applied in TD School courses, such as frame creation and double-loop learning, enable project participants to question underlying premises and assumptions in a safe and supportive environment. Guidance is given to both partners and students on ways to handle these potentially-sensitive conversations. Double-loop learning is a good example of an approach that cuts across multiple frameworks, with origins in organisational learning (Argyris and Schön 1996) and subsequent application to both transformative learning (Boström et al. 2018) and transdisciplinarity (Polk and Knutsson 2008). Reframing also enables critical reflection, with the approach taken in TD School cutting across all three types of critical reflection advocated by Leal Filho et al. (2018); that is, content reflection that focuses on how a problem is described, process reflection that focuses on problem-solving strategies and premise reflection in which the problem itself is questioned.

The transdisciplinary focus on inclusion of multiple knowledge types and perspectives is translated into practice in TD School through the use multi-disciplinary student teams, bringing industry and community partners into the university environment and consideration of under-represented knowledge types, such as Indigenous knowledges. Elias (1997) argues that this exposure to alternative viewpoints and experiences, in combination with "consciously directed processes" of critical analysis and reflection are essential for transform one's own assumptions and worldviews. Peer learning in multi-disciplinary teams is also a key component in the Transformative Innovation Labs that have been piloted in Germany, although there is also potential to further enhance exposure to diverse perspectives at TD School by drawing on examples such as the "Global Classroom" at Leuphana University (Germany) and Arizona State University (USA), which focuses on bringing together students from diverse cultural backgrounds to address sustainability challenges (Wanner et al. 2020).

The transcendence of traditional roles and the creation of "third spaces" for mutual learning have been employed in TD School to enable the critical assessment of received assumptions and underlying premises necessary for transformative learning (Mezirow 1991). In their "pledge for a transformative science", Schneidewind et al. (2016) highlight the importance of breaking with traditional understandings of the roles of scientists (as experts) and lay people (as research subjects). They advocate for the creation of "real-world labs", which could be an alternative framing employed in future for the TD School's "complex challenges". Another focus area that has been identified in TD School for increasing transformative potential is enhancing the link between the transdisciplinary research projects that its academic staff engage in and the transdisciplinary learning programs in which partners set challenges for students.

Urban sustainability challenges present important opportunities for students to unpack the complexity of systems they are familiar with and issues they are directly affected by. As with reflexivity and real-world challenges, complexity has been highlighted as a critical consideration for both transdisciplinary approaches (Popa et al. 2015) and transformative learning (Wanner et al. 2020). By applying concepts such as causal loops, resilience and leverage points to urban sustainability challenges, a reinforcing feedback loop can be created whereby learners are better equipped to unpack the complexity of the systems they live in, which in turn can reveal alternative perspectives and framings of the challenges they face, which in turn reveals new sources of complexity to be analysed. This opens up the potential for existing paradigms to be transcended and for students, partners and researchers to go beyond double loop learning to achieve triple loop learning that opens up sustainability issues to new ways of thinking and action (Fazey et al. 2018).

Further opportunities to adapt TD School's approach to transformative and transdisciplinary learning have been identified during the COVID-19 pandemic. This major system disruption turned students' own lives into a "real-world lab" and enabled practical and relevant examples of urban transformation to be used in classroom activities. However, it also created challenges in relation to bringing diverse stakeholders into the classroom, which had predominantly been done face-to-face in TD School prior to the pandemic. Online learning rose to prominence globally in universities in response to the pandemic (Stone 2017), initially in the form of "emergency e-learning" (Murphy 2020) and then through more measured and analytical approaches around the world (Butler-Henderson et al. 2020). Going forward, online learning could enhance opportunities to bring diverse stakeholders into university learning activities by reducing barriers relating to travel or the ability to take time off from other responsibilities. Online tools can also enhance the ability to record and document collaborations taking place between diverse stakeholders, thus enabling reflexivity and double loop learning by allowing past conversations and decisions to be revisited.

Conclusion

The case study presented in this article demonstrates a number of ways in which the adoption of transdisciplinary approaches can enable transformative learning around urban sustainability in higher education. The insights provided through this case study add to those generated by other research into higher education programs that combine transdisciplinarity, transformative learning and urban sustainability across Europe, Africa, Asia and South America. This research has demonstrated how exposure to diverse knowledges and viewpoints and analysis of the full complexity surrounding to real-world challenges can contribute to the critical analysis and reflexivity necessary for transformative learning. The lessons highlighted in this article demonstrate that, in order to achieve a genuinely transdisciplinary approach to transformative learning, educators need to not only enable students to obtain a transdisciplinary skillset (e.g. by learning methods and gaining practical experience) but also to apply a transdisciplinary mindset to the way they approach learning design (e.g. by co-creating curriculum, drawing on diverse perspectives, reframing traditional relationship dichotomies and embracing the uncertainty and complexity of the real world in which learning takes place).

Achieving transdisciplinary learning faces a number of challenges in universities, such as addressing gaps in knowledge amongst teaching staff, finding the resources to bring so many people together, and overcoming traditional university structures that can create "silos" of

knowledge and prescribe fixed roles for teachers, students, researchers and outside partners. However, where such challenges are able to be overcome through adequate resourcing, a commitment to a transdisciplinary vision and the application of critical analysis and reflexivity to our own processes, the potential exists to greatly increase the application of transdisciplinary practices in higher education. In turn, this may enable not only transformative learning amongst our students, but transformations in the ways in which we approach sustainability challenges in our cities more broadly.

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References

Ahern, J. (2011). From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. *Landscape and Urban Planning, 100*(4), 341-343, doi:https://doi.org/10.1016/j.landurbplan.2011.02.021.

Argyris, C., & Schön, D. A. (1996). *Organizational Learning 2: Theory, Method, and Practice*. Reading, MA: Addison-Wesley, Reading.

Baumber, A., Kligyte, G., van der Bijl-Brouwer, M., & Pratt, S. (2020). Learning together: a transdisciplinary approach to student–staff partnerships in higher education. *Higher Education Research & Development, 39*(3), 395-410, doi:10.1080/07294360.2019.1684454.

Boström, M., Andersson, E., Berg, M., Gustafsson, K., Gustavsson, E., Hysing, E., et al. (2018). Conditions for Transformative Learning for Sustainable Development: A Theoretical Review and Approach. *Sustainability, 10*(12), doi:10.3390/su10124479.

Burger, P., & Kamber, R. (2003). Cognitive integration in transdisciplinary science: Knowledge as a Key Notion. *Issues in Integrative Studies, 21*, 43-73.

Butler-Henderson, K., Crawford, J., Rudolph, J. r., Lalani, K., & Sabu, K. M. (2020). COVID-19 in Higher Education Literature Database (CHELD V1): An open access systematic literature review database with coding rules. *Journal of Applied Learning & Teaching, 3*(2), 1-6.

Carpenter, S. R., Arrow, K., Barrett, S., Biggs, R., Brock, W., Crépin, A.-S., et al. (2012). General Resilience to Cope with Extreme Events. *Sustainability, 4*(12), 1-12.

Dorst, K. (2015). *Frame Innovation: Create New Thinking by Design*. Cambridge, MA, USA: MIT Press.

Elias, D. (1997). It's time to change our minds. *ReVision, 20*(1), 2-7.

Evans, T. L. (2015). Transdisciplinary collaborations for sustainability education: Institutional and intragroup challenges and opportunities. *Policy Futures in Education, 13*(1), 70-96, doi:10.1177/1478210314566731.

Fam, D., Palmer, J., Riedy, C., & Mitchell, C. (Eds.). (2017). *Transdisciplinary Research and Practice for Sustainability Outcomes*. Oxford: Earthscan from Routledge.

Fazey, I., Schäpke, N., Caniglia, G., Patterson, J., Hultman, J., van Mierlo, B., et al. (2018). Ten essentials for action-oriented and second order energy transitions, transformations and climate change research. *Energy Research & Social Science, 40*, 54-70, doi:https://doi.org/10.1016/j.erss.2017.11.026.

Jahn, T., Bergmann, M., & Keil, F. (2012). Transdisciplinarity: Between mainstreaming and marginalization. *Ecological economics, 79*, 1-10, doi:https://doi.org/10.1016/j.ecolecon.2012.04.017.

Jantsch, E. (1972). Towards interdisciplinarity and transdisciplinarity in education and innovation. In L. Apostel, G. Berger, A. Briggs, & G. Michaud (Eds.), *Interdisciplinarity, problems of teaching and research in universities* (pp. 97-121). Paris: OECD Publications.

Klein, J. T. (2017). Patterns of definition. In D. Fam, J. Palmer, C. Riedy, & C. Mitchell (Eds.), *Transdisciplinary Research and Practice for Sustainability Outcomes* (pp. 7-21). Oxford: Earthscan from Routledge.

Kligyte, G., Baumber, A., van der Bijl-Brouwer, M., Dowd, C., Hazell, N., Le Hunte, B., et al. (2019). "Stepping in and stepping out": Enabling creative third spaces through transdisciplinary partnerships. *International Journal for Students As Partners, 3*(1), 5-21, doi:https://doi.org/10.15173/ijsap.v3i1.3735.

Leal Filho, W., Raath, S., Lazzarini, B., Vargas, V. R., de Souza, L., Anholon, R., et al. (2018). The role of transformation in learning and education for sustainability. *Journal of Cleaner Production, 199*, 286-295, doi:https://doi.org/10.1016/j.jclepro.2018.07.017.

Max-Neef, M. A. (2005). Foundations of transdisciplinarity. *Ecological economics, 53*(1), 5-16.

Meadows, D. H. (2008). *Thinking in systems: a primer*. White River Junction: Chelsea Green Publishing Company.

Mezirow, J. (1991). *Transformative dimensions of adult learning*. San Francisco: Jossey-Bass.

Murphy, M. P. A. (2020). COVID-19 and emergency eLearning: Consequences of the securitization of higher education for post-pandemic pedagogy. *Contemporary Security Policy, 41*(3), 492-505, doi:10.1080/13523260.2020.1761749.

Petra, B., & Christian, R. (2017). Transdisciplinary learning and teaching as answers to urban sustainability challenges. *International Journal of Sustainability in Higher Education, 18*(1), 63-83, doi:10.1108/IJSHE-04-2015-0078.

Piaget, j. (1972). The epistemology of interdisciplinary relationships. In L. Apostel, G. Berger, A. Briggs, & G. Michaud (Eds.), *Interdisciplinarity: problems of teaching and research in universities* (pp. 127–139). Paris: OECD.

Polk, M. (2015). Transdisciplinary co-production: Designing and testing a transdisciplinary research framework for societal problem solving. *Futures, 65*, 110-122, doi:https://doi.org/10.1016/j.futures.2014.11.001.

Polk, M., & Knutsson, P. (2008). Participation, value rationality and mutual learning in transdisciplinary knowledge production for sustainable development. *Environmental Education Research, 14*(6), 643-653, doi:10.1080/13504620802464841.

Popa, F., Guillermin, M., & Dedeurwaerdere, T. (2015). A pragmatist approach to transdisciplinarity in sustainability research: From complex systems theory to reflexive science. *Futures, 65*, 45-56, doi:https://doi.org/10.1016/j.futures.2014.02.002.

Prokopenko, M. (2014). On the Cross-Disciplinary Nature of Guided Self-Organisation. In M. Prokopenko (Ed.), *Guided Self-Organization: Inception* (pp. 3-15). Verlag: Springer.

Schneider, F., Giger, M., Harari, N., Moser, S., Oberlack, C., Providoli, I., et al. (2019). Transdisciplinary co-production of knowledge and sustainability transformations: Three generic mechanisms of impact generation. *Environmental Science & Policy, 102*, 26-35, doi:https://doi.org/10.1016/j.envsci.2019.08.017.

Schneidewind, U., Singer-Brodowski, M., Augenstein, K., & Stelzer, F. (2016). Pledge for a transformative science : a conceptual framework. *Wuppertal papers* (Vol. 191). Wuppertal: Wuppertal Institute for Climate, Environment and Energy.

Scholz, R., & Steiner, G. (2015). The real type and ideal type of transdisciplinary processes: part I—theoretical foundations. *Sustainability Science 10,* pp. 527-544, doi: https://doi.org/10.1007/s11625-015-0326-4

Stankey, G. H., Clark, R. N., & Bormann, B. T. (2005). Adaptive management of natural resources: theory, concepts, and management institutions. (pp. 73). Portland, OR, USA: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Stone, C. (2017). Opportunity through online learning: Improving student access, participation and success in higher education. (pp. 85). Perth: National Centre for Student Equity in Higher Education.

Suárez, M., Gómez-Baggethun, E., & Onaindia, M. (2020). Assessing socio-ecological resilience in cities. In M. A. Burayidi, A. Allen, J. Twigg, & C. Wamsler (Eds.), *The Routledge handbook of urban resilience* (pp. 197-216). Abingdon, Oxon: Routledge.

United Nations (2019). World Urbanization Prospects 2018: Highlights. . (pp. 38). New York: United Nations, Department of Economic and Social Affairs, Population Division.

UTS (2021). UTS 2027 Strategy: Our values. https://www.uts.edu.au/about/uts-2027-strategy/our-values (Accessed: 21 July 2021, Updated: 10 January 2019)

Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social–ecological systems. *Ecology and Society, 9*(2), 5.

Wanner, M., Schmitt, M., Fischer, N., & Bernert, P. (2020). Transformative innovation lab : handbook to facilitate students' real-world laboratory projects to promote transformative and transdisciplinary competencies. Wuppertal: Wuppertal Institut für Klima, Umwelt, Energie.