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Design principles for advancing higher education sustainability learning through transformative research

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Abstract

A growing number of transformative research practices that redefine the role of science in engaging with local—mostly urban—transformation processes have emerged in recent decades. However, while education is considered a key driver for sustainability transformations, higher education has been slow to develop and implement dedicated, appropriate and effective transformative education programmes and learning modules. In this paper, we present a framework of design principles for transformative learning modules in higher education. These principles are derived from two growing discourses: higher education *sustainability learning*, and *transdisciplinary and transformative research*—both of which are centrally anchored in the field of sustainable development and sustainability science. The principles presented provide guidance for course leaders in higher education to create learning modules aimed at enabling students to become engaged in transdisciplinary and transformative research that fosters sustainability transitions in local and urban contexts. We use the Transformative Innovation Lab (TIL)—a learning course developed and tested at two German universities—as an example of how the design principles can be applied. The module, which runs over two semesters, supports Masters students in their process of developing real-world laboratories and exploring urban sustainability transitions through collaborative experimentation with local practice partners. We discuss the factors that enable and limit the implementation of transformative learning modules and outline aspects of the novel roles adopted by lecturers in transformative teaching environments. Moreover, we highlight the need for both institutional change and transformative teaching formats that go beyond transformative research as key for driving universities to take responsibility for collaboratively fostering sustainability transitions in their local contexts.

Keywords Higher education sustainability learning · Transformative learning · Transformative research · Transdisciplinarity · Real-world laboratories · Design principles

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1 Introduction

There is widespread consensus that education can be a key driver in enabling people to actively steer transition processes (Brundiers et al., 2021; Sterling et al., 2017). However, to achieve this potential, new transformative education programmes that complement the traditional disciplines are needed to better empower people across all age groups to contribute to sustainability transitions (Lange, 2012). Through its close links to the sciences, higher education is traditionally considered to be at the forefront of such developments and recent reforms, such as the Bologna process in Europe, have contributed to a higher degree of flexibility in this domain (Barth, 2016). Over the past two decades, universities and higher education institutions have begun to redefine their role in driving and supporting sustainable development. Moving beyond simple economy-driven technological knowledge transfer, an increasing number of universities are engaging in co-creative sustainability transition projects in order to transform their own cities and regions (Trencher et al., 2014). Many of these projects employ experimental approaches, such as urban or sustainable living laboratories, urban transition laboratories, real-world laboratories or similar (for an overview see McCrory et al., 2020). Some temporarily use the installed laboratory as a learning environment for students. However, few universities have introduced ongoing and structured sustainability-oriented programmes of study that use these formats and educate students in higher education to use transformative research approaches to deal with sustainability problems, analyse them and contribute to solutions (Evans et al., 2015; Larsson & Holmberg, 2018; Pohl et al., 2018). Such programmes are rare compared to programmes rooted in traditional scientific disciplines (Weiss & Barth, 2019). Furthermore, few of the available programmes include modules based on research approaches, such as real-world laboratories and experiments, despite the recent call for a stronger orientation towards the generation of action-oriented knowledge for sustainability (Caniglia et al., 2020). Overall, such education programmes—and the relevant guidance for their development—is lacking. Therefore, in this paper, we draw on discourses around *sustainability learning* and *transdisciplinary and transformative research*. Based on these recent theoretical and conceptual approaches, we derive design principles. The principles provide guidance for educational practitioners who want to educate students to generate action-oriented knowledge in local contexts by developing and conducting transformative research in small-scale real-world laboratories. The principles were originally developed in the context of a three-year research and teaching project and guided the design of the Transformative Innovation Lab (TIL) learning module. We share insights from the TIL to illustrate how the design principles can be applied. Reflecting on the principles and our experiences in the TIL, we discuss the challenges and opportunities of the application of such learning formats for both lecturers/tutors and institutions and their potential to foster urban transitions.

2 Learning and researching for sustainability transformations

In the context of the ongoing discussion around sustainability and sustainable development (e.g. Grunwald & Kopfmüller, 2012), a wide range of concepts have emerged in terms of integrating sustainability-oriented education into higher education. Two strands of research and practice figure prominently, which share many links and commonalities. *Sustainability learning* in higher education is largely based on contributions from educational science and

provides an innovative impetus to higher education by integrating sustainability. *Transdisciplinary and transformative research* forms a new research mode which has introduced the question of how and to what extent higher education contributes to sustainable development in society. The following sections provide a brief overview of these concepts in terms of their approaches to transformative learning programmes and associated insights.

2.1 Sustainability learning in higher education

The implementation of sustainability learning in higher education has proved that innovation can be brought about by new areas in teaching and learning and can create new ideas and formats by introducing new methods or new learning settings. By ‘doing things differently’, sustainability learning has provided answers to some of today’s expectations of higher education, namely through its interdisciplinary nature, its intercultural dimension and its transdisciplinary orientation (Barth, 2016). This is particularly visible in its contributions to problem-based and project-based learning where higher education introduces complex real-world problems and a strong solution orientation (Brundiers & Wiek, 2013; Tejedor et al., 2019), as well as in engagement-oriented formats such as service learning which are further developed through integrating transdisciplinary learning (Barth et al., 2014; Stauffacher et al., 2006). More recently, sustainability learning has been drawing from transformative learning theory, questioning the intent and outcomes of the traditional learning and teaching approaches of higher education and Education for Sustainable Development (ESD) (Rodríguez Aboytes & Barth, 2020; Singer-Brodowski, 2016a, 2016b). The approach was originally introduced by Mezirow in the context of personal development and adult learning (Mezirow, 1991). It aims to foster “autonomy, individuation, empowerment, ecological consciousness, social action, citizenship and democracy” (Cranton & King, 2003; Mezirow, 1997, 2003; as cited in Rodríguez Aboytes & Barth, 2020, p. 996) by transforming problematic frames of reference, namely fixed “habits of mind, meaning perspectives and mindsets” (Mezirow, 2003, p. 58). Transformative learning adds to sustainability learning by explicitly addressing and critically reflecting on underlying moral assumptions and embracing diverse knowledge and experiences (Brookfield, 2000, p. 130).

The above-mentioned efforts have been accompanied by a growing body of research, which offers insights into learning outcomes and processes. Learning objectives as the intended learning outcomes of higher education for sustainable development are still discussed with reference to the foundation documents of the United Nations Educational Scientific and Cultural Organization (UNESCO). These documents advocate for the capabilities of active societal participation and life-long learning (UNESCO, 2005). In the literature on education for sustainable development, several approaches share the UNESCO vision of enabling people and specify the learning objectives as the knowledge, skills, and attitudes for the transformation towards sustainability (de Haan, 2008; Rieckmann, 2012; Stibbe, 2009). These contributions use various concepts for defining skills, literacy, competencies, or capabilities (Barth, 2016). Against the background of this diversity, agreement has been growing that the sought-after outcomes should be framed around key competencies in sustainability, defined as “complexes of knowledge, skills, and attitudes that enable successful task performance and problem solving with respect to real-world sustainability problems, challenges, and opportunities” (Wiek et al., 2011, p. 204).

With respect to learning processes, researchers have elaborated on the need for novel teaching and learning settings to support the development of sustainability competencies (Rowe, 2007; Sterling & Thomas, 2006). Problem-based and project-based learning

(Brundiers & Wiek, 2013; Dale & Newman, 2005) in general, with adaptations such as design charrettes (Foley et al., 2017) and real-world laboratories (Singer-Brodowski et al., 2018), figure prominently in such settings and provide examples of how to help students experience sustainability problems and make first-hand contributions to solutions. It is reasoned that these teaching and learning settings provide students with opportunities to contend with the complexity of sustainability problems and develop viable solution options. Consequently, how to design such teaching and learning settings as open learning environments is the subject of much debate.

2.2 Transdisciplinary and transformative research

The question of the contribution that science can make to overcoming global challenges is a leitmotif of sustainability research. The need to develop adequate approaches for tackling sustainability problems has led the scientific community to enter a profound reflection process, discussing solution-oriented and interventional research designs. One of the most influential contributions stemming from this debate was the proclamation of the so-called Mode-2 research approach (Gibbons et al., 1994; Nowotny et al., 2001). This stimulated the discourse around transdisciplinary research, which subsequently developed into a core research practice in the field of sustainability. Transdisciplinary research takes societal problems as a starting point and integrates various disciplinary bodies of knowledge and practical experience and wisdom, with the aim of producing socially robust knowledge. Frameworks, concepts, guidelines, and quality standards have been developed for transdisciplinary research (Bergmann et al., 2005; Hirsch Hadorn et al., 2006; Jahn et al., 2012; Klein, 2006; Lang et al., 2012; Scholz et al., 2006), and international scientific networks and programmes for studying the earth sciences and social sciences have called for greater transdisciplinary activity in order to co-create sustainability knowledge (Mausser et al., 2013). Following a similar line of thought, the German Advisory Council on Global Change has characterised two specific research approaches: transformation research, which focuses on describing, analysing, and explaining global change processes, and transformative research, which engages with current debates and actions to actively strengthen sustainable development (WBGU, 2011). In related fields, scholars and practitioners have developed intervention-focussed approaches, building on and calling for an experimental turn in the social sciences (Overdevest et al., 2010). Blending experience from decades of (participatory) action research (Kemmis & McTaggart, 2000; Ozanne & Saatcioglu, 2008), concepts of transition management, strategic niche management (Kemp et al., 1998, 2007) and new experimental modes, a broad range of action-oriented formats such as (urban/sustainable) living laboratories (Liedtke et al., 2015; Voytenko et al., 2016), urban transition laboratories (Nevens et al., 2013), transformation laboratories (Pereira et al., 2020), and real-world laboratories (Parodi et al., 2018; Schneidewind, 2014) have been established. Many of these explicitly focus on urban areas as spaces and loci with pressing sustainability issues of high complexity but also with significant opportunities for creativity: an atmosphere conducive to innovation and a critical mass of progressive change agents and early adopters. Among these approaches, the real-world laboratory discourse is closest to fulfilling the transdisciplinary quality criteria. The concepts of ideal-type processes (Wanner et al., 2018) and success factors (Bergmann et al., 2021) were developed to create actionable real-world laboratory settings. Luederitz et al. (2017) and Caniglia et al. (2017) contributed a formative evaluation scheme and a typology embedding real-world experiments into the experimental methodology of sustainability research.

However, despite the establishment of such action-oriented knowledge research approaches over the past decade (Caniglia et al., 2020), higher education institutions have not yet systematically harnessed their potential as learning environments (Singer-Brodowski et al., 2018).

3 Design principles

While theoretical discussions around sustainability learning in higher education have introduced valuable learning and teaching concepts, incorporating such approaches into higher education programmes remains a challenge for both programme directors and lecturers. The theoretical concepts presented in the preceding section of this paper represent our understanding of the central approaches in this field.

This literature base was crucial for informing the development of the TIL that we implemented in two different universities over two years. A more detailed presentation of the TIL is provided in chapter 4.

In this paper, we address the question of how the literature can inform the development of courses in contexts beyond the pilot study programmes at the two universities where we applied our course design. We identify principles that can inform other courses by making sense of the broad discussions found in the literature for educators in the field. In this section, we present a comprehensive set of principles for sustainability-oriented courses building on transformative learning and transformative research approaches.

The framework is designed to provide a point of reference for reflection when designing and teaching such study courses. From our experience, the reality of developing learning modules and teaching these courses involves careful planning beforehand and constant re-adjustment during the semester(s). Our design principles offer a framework to support lecturers (and students) during both phases to better integrate the theoretical advancements of sustainability learning and transdisciplinary and transformative research into the courses.

Our suggested set of eight coherent design principles was developed through extensive joint interdisciplinary discussion, which built on the reflection of our experiences from teaching in the TIL, discussions with peer course leaders regarding the purpose of such design principles and a deep re-examination of the literature used for the TIL design.

To make the development process of the suggested principles and their rootedness in the literature transparent, we adopted a Sankey-style diagram to illustrate our thought process (see Fig. 1). This shows the principles on the right-hand side and the discourses that informed these principles on the left.

The eight principles depicted in the Sankey-style diagram (Fig. 1) are considered as a coherent set, and thus, each principle has equal importance for the design of the module as a whole. The design principles complement each other: they are strongly interlinked and influence the general course design as well as specific learning modules and the single activities within them. Consequently, we chose to depict each design principle the same size (right-hand column). However, they differ with regard to the number of discourses they are informed by, which explains why the source nodes differ in size (left-hand column). Neither the size of the nodes nor the width of the flows should—or could—be interpreted quantitatively.

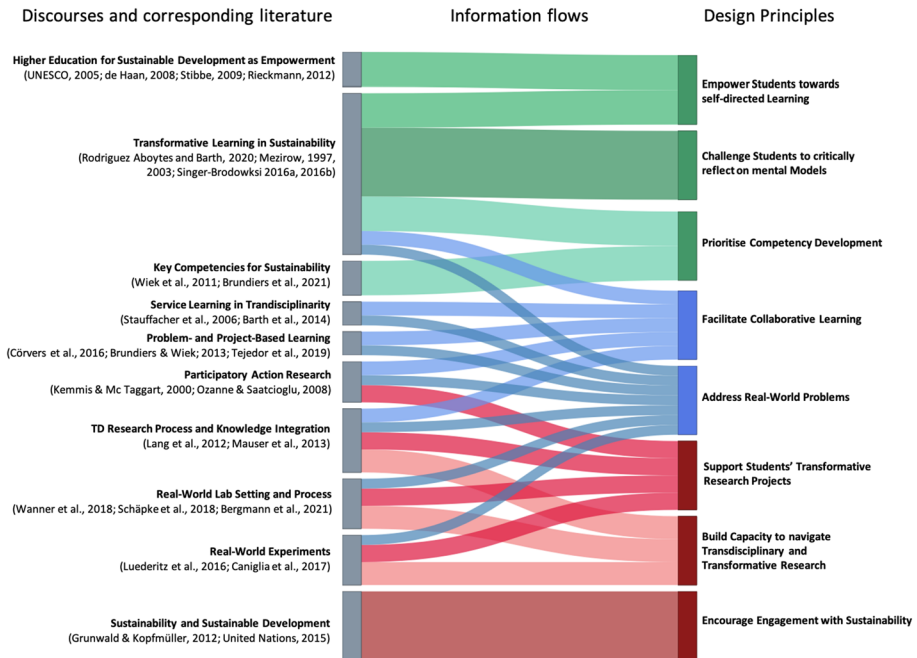


Fig. 1 Sankey-style diagram of eight design principles for higher education sustainability learning through transformative research (right) and their corresponding roots in discourses and the literature (left). Colours (green, blue, and red) refer to the clustering of the eight principles in three key areas of course design: green = teaching mindset, blue = learning environment, red = research activities (see also Fig. 2)

3.1 Design principles in detail

In the following section, we outline and explain the principles in more detail. The principles are formulated as guidance for those responsible for course design and are clustered according to the higher-level key areas of course design. *Teaching mindset* refers to the specific attitude towards learning, the course, and the students that course leaders should take account of when designing and delivering a course. This mindset could—depending on personal teaching style—differ significantly from ‘classic’ approaches to teaching. *Learning environment* emphasises the setting, atmosphere, and context for the course as part of the design. The principles to consider in this area could include how to arrange the teaching/learning space or who to employ to deliver the course.

The area of *research activities* relates closely to the course content and focuses on topics, themes, and activities that are central for transformative education courses (see Fig. 2).

3.1.1 Teaching mindset

3.1.1.1 Empower students towards self-directed learning Sustainability learning (and higher education for sustainable development) aims to empower students towards self-directed learning from a procedural perspective (UNESCO, 2005). Consequently, the role of the course leader is to develop an inspiring learning environment (Singer-Brodowski



Fig. 2 Depiction of the eight design principles for higher education sustainability learning through transformative research (outer ring) and their superordinate key areas of course design (inner ring). The circular arrangement without hierarchy or numbering is intended to depict our understanding of all the principles as being part of a coherent and equally important set

et al., 2018) and to create adequate learning opportunities, rather than to focus on specific content inputs (de Haan, 2008; Rieckmann, 2012; Stibbe, 2009). It is crucial to foster an empowering teaching mindset towards students, encouraging them to take responsibility for their own learning journey while providing a safe space to learn in experimental settings. This includes guidance for reflection, as well as self-care and emotional coping strategies.

3.1.1.2 Challenge students to critically reflect on mental models Following the theoretical considerations of transformative learning discourses, students should be challenged to reflect on the content, processes, and premise of their own mental models (Mezirow, 1997, 2003; Singer-Brodowski, 2016a, 2016b). For students to be able to reflect on sustainability issues, the ability to critically reflect on their own presuppositions is considered crucial. However, transformative learning should not only be considered a means of achieving transformative action but also as an aspiration in itself (Rodríguez Aboytes & Barth, 2020).

3.1.1.3 Prioritise competency development Teaching in higher education sustainability learning contexts is competency-oriented, with the aim of enabling students to address sustainability problems and contribute to their solutions as change agents. Competency development as a learning goal should guide the design of learning modules as a whole and the

selection of formats and the arrangement of specific learning units. The focus on competency development should be communicated transparently and be adequately represented through reflexive examination approaches. Key competencies in this context include normative competence, systems thinking competence, interpersonal competence, anticipatory competence, and strategic competence (Brundiers et al., 2021; Wiek et al., 2011).

3.1.2 Learning environment

3.1.2.1 Facilitate collaborative learning Collaborative learning is a key feature of transformative learning modules in higher education. For students to benefit from collaboration with their peers, adequate formats should be established for students to meet together, and discussions should be facilitated by lecturers (Cörvers et al., 2016; Stauffacher et al., 2006). Collaboration opportunities in multi-stakeholder settings should be supported by providing contact with practitioners and training exercises for collaborative methods.

3.1.2.2 Address real-world problems Engaging with actual real-world problems is a crucial feature of learning modules that aim at transformative learning and competency development through transformative research. Identifying manageable local challenges for students to engage in and developing trusted relationships with practitioners are crucial factors for creating spaces where students can learn. Actively managing the expectations of both students and practitioners allows for the development of collaborative settings where failure can be embraced without negative consequences.

3.1.3 Research activities

3.1.3.1 Support students' transformative research projects Lecturers in transformative research-oriented learning environments must play the key role of supporting students in the design and realisation of their own projects. Regular individual and group sessions with students allow for the joint critical reflection of research and experiment designs. Offering entry points to a demanding research process by inviting students into established collaborative research settings allows students to quickly engage with actors and build on trusted relationships. Lecturers must take on the role of coaches who closely accompany students, react quickly to their challenges, and respond adequately to specific and individual questions.

3.1.3.2 Build the capacity to navigate transdisciplinary and transformative research To be able to create their own transformative research projects, students need to develop the ability to navigate the discourses of transdisciplinary and transformative research approaches. Students need to be supported to position their work within the current discourse and build on established concepts in this field of research. This includes reflecting on the normative and ethical implications of transformative research. A particular focus lies on familiarising students with methods and approaches that can inform their research, such as methods of collaboration with practice partners, the design of interventions, and knowledge integration.

3.1.3.3 Encourage engagement with sustainability The discourse around sustainability encompasses a wide field of concepts and topics; consequently, critical engagement with different notions and issues should be encouraged. Jointly exploring, discussing, and reflecting on own perceptions, theoretical concepts (Grunwald & Kopfmüller, 2012) and

political frameworks (e.g. Sustainable Development Goals (SDGs)) (UN, 2015) allow students to position themselves and their research. This enables students to identify motivating and challenging topics with which to engage.

4 Applying the design principles: the example of the Transformative Innovation Lab (TIL)

Project context The TIL was developed as part of the EEVA project (the development, testing, and dissemination of new qualification offer for ‘change agents’ for transformative learning using the real-world laboratory approach). In two pilots, a TIL was integrated into the Futures Studies Masters programme at Freie Universität Berlin and the Sustainability Science Masters programme at Leuphana University Lüneburg. The project was coordinated by the Wuppertal Institute and ran from 2017 to 2020 and was funded by the German Federal Environmental Foundation (DBU). Two student cohorts with 34 students in total participated in the TIL pilots.

Over the course of the project and based on joint reflection with our students and their feedback, the teaching approach was iteratively improved. Following the conclusion of the project, we can present the TIL as a promising approach for realising many of the aspects discussed in the literature around sustainability learning, transformative research, and sustainability. The project outcomes have since inspired discussions on transformative research practices in the German sustainability learning community.

4.1 Applying the design principles to the overall course design

To illustrate how the design principles can be applied, the following section builds on our experience in designing and conducting a higher education teaching module as part of the three-year EEVA research project (Wanner et al., 2021a, 2021b). The TIL was designed as an experimental space offering a safe environment in which students could explore both themselves and the transformative research approach as potential sustainability change agents. Students from two different Masters programmes at two German universities were jointly invited to develop their own real-world laboratories and explore sustainability transitions through collaborative experimentation with local practice partners.

We designed the course to focus on the learning process, building on transdisciplinary and transformative research processes as a guiding structure. The practical engagement of students in a *real-world context and with real-world problems* formed our starting point. From the outset, students were encouraged to identify and engage with real-world sustainability problems in their respective local contexts, e.g. sustainable mobility, the role of church communities as drivers of sustainability transformations or renewable energy transitions in local economies. Over the course of the seminar, students worked on their *own transformative research projects*, with the aim of developing research projects that contributed to the solution of sustainability problems. We guided the students, step by step, in developing and realising their own research projects, linking *engagement with sustainability*, building the *capacity to navigate the discourses and methodologies of transdisciplinary and transformative research* to the students’ own research activities.

In the learning environment we designed, we focussed strongly on the *development of competencies*, both through dedicated exercises and by transferring the learnings to students' own projects. The hands-on approach that our students followed in designing and planning their own research projects with partners was a central feature of the course design, which enabled competency development in and through transdisciplinary collaboration.

We aligned inputs, critical discussions, and options for reflection and feedback needed to support the students in each step. Through a variety of formats, we *challenged students to make their own mental models explicit*, to take a critical stance towards theories and methodologies and to reflect on their own processes and individual developments.

Furthermore, the TIL encompassed continuous reflection and feedback within the teaching team and between the teaching team and the students, which also supported the iteration of the course design. We explicitly integrated the different competencies, knowledge areas, and needs of the group (including the teaching team) and built on teamwork and peer exchange (e.g. the formation of small student groups for feedback and support) to *foster a collaborative learning setting*. The open reflection and exchange on the course development and the peer feedback contributed to creating a safe learning setting for the students that allowed for failures and redesigns, thereby supporting the *empowerment of the students* to set their own goals and directions for their learning journey.

4.2 Example: a kick-off retreat as the foundation for a transformative sustainability learning process

The following section describes the kick-off of the TIL to illustrate the application of the principles within a single learning unit of the TIL. It complements the description (above) of how the principles are applied within the general course design. For a detailed description of the TIL and its modules, please refer to the handbook (Wanner et al., 2020) and the bi-lingual overview article (Wanner et al. 2021a, 2021b). Rather than connecting single aspects of this learning unit to specific design principles, we want to highlight how the principles support the design of such a learning unit and help to lay a foundation for applying the principles within the whole course.

The TIL started with a five-day kick-off retreat in which the group of 20 students from different Masters programmes and the interdisciplinary teaching team gathered at a hostel in a rural location. The kick-off was crucial for setting the overall atmosphere and framework for the TIL. Part of the aim of the retreat was to establish common (theoretical) ground and to find starting points for the students' own research projects. However, the overriding purpose of the kick-off retreat was to allow everyone to experience a specific teaching and learning mindset and learning environment. Consequently, getting to know each other and developing an atmosphere of trust were central aspects of the kick-off. Therefore, we dedicated time to team building exercises, peer exchange, and group dynamics in general and ensured that the students were invited not only to design their own learning journeys, but also to co-design our kick-off.

The activities at the kick-off retreat combined multiple principles, which interlinked mindset, learning environment, and transformative research activities. For example, we played a simulation game in which students adopted different roles in fictitious countries, trying to balance well-being, economic development, and natural resource consumption. This game combined team building, engagement with sustainability discussions, systems thinking, and team competency training and allowed for critical (self-) reflection. It also

fostered a collaborative learning setting and supported an atmosphere of experimentation, mutual trust, and open (self-) critical discussion.

We also established a common understanding of transformative research. We combined inputs from teachers and students, invited discussions and presentations of existing knowledge, and facilitated peer exchange. We used a 'buzzword-bingo' game to create a safe space for asking questions that might otherwise seem too obvious to ask, with the aims of fostering critical discussion of concepts and theories and of identifying potential topics for subsequent inputs. Moreover, we combined theoretical aspects with input from guest speakers' case studies, transferring theory to practical examples. To enable self-directed learning, we prepared some of the basic input and planned time for emerging topics.

To kick-off the project work, we started by asking the students to personally reflect on their favourite SDG. This exercise engaged students in sustainability discussions and supported them to find an anchor point for research into real-world sustainability challenges. This activity simultaneously served as a team-building exercise to connect students who shared similar interests, which supported subsequent project team formation. With a first direction in mind, we invited students to a 'fast forward exercise'. In groups, they 'ran' through a transformative research project in the fashion of a thought experiment. They started by brainstorming and choosing a real-world problem, before brainstorming different potential practice partners and stakeholders, deliberately ranging from close and easily accessible ones to actors out of their reach. After discussing potential practical issues for a selected stakeholder, the students brainstormed potential interventions and experiments, again ranging from the small and easy to a large-scale real-world laboratory. Finally, the students jointly discussed how they could evaluate, measure, and document this process from the perspective of scientific research requirements. This exercise, again, supported team building, translated theoretical and methodological concepts into the TIL environment, fostered strategic competencies, and encouraged the students in their own research work.

These examples illustrate that applying the principles means approaching the course design with a simultaneous focus not only on the content needed to enable the students' project work, but also on the collaborative and safe atmosphere and how to foster the emergence of individual learning journeys.

5 Discussion

In this discussion, we reflect on three critical aspects involved in advancing sustainability learning in higher education through transformative learning and transformative research: (1) the challenges for course leaders and students in such learning formats; (2) the potential and limitations of the presented principles for designing learning modules; and (3) the importance of such learning formats for universities to adopt new roles as drivers of urban sustainability transitions.

5.1 What purpose do the design principles serve?

The design principles aim to support programme directors and lecturers in higher education institutions to implement sustainability learning-oriented courses by building on transformative learning and transformative research. Both concepts are considered crucial for fostering sustainability transformations. On an individual level, transformative learning

builds capacities to reflect on and actively address sustainability problems. In a complementary way, transformative research involves designing transition processes and generates robust knowledge based on interventions.

However, implementing courses that integrate these perspectives is challenging due to institutional inertia and the demanding complexity of teaching in such settings. We deem these to be the main reasons why the various pilot projects and experimental teaching modules that have been developed have only occasionally been transferred into regular curricula and teaching culture (Dabaieh et al., 2018; Pfau & Uhl, 2018).

In this context, the design principles serve two purposes. First, as a comprehensive set, the principles allow for the holistic planning of courses without having to reinvent the wheel and without being overly specific to a single context or location. Second, the principles serve as a tool for reflection during the teaching phases of other pilots or current modules, offering orientation and areas for discussion concerning crucial teaching and research concepts.

Therefore, the strength of the design principles lies in a high degree of practicality, which makes the highly advanced discourses of sustainability learning theory and transformative research accessible. While a course that is designed according to single principles can already contribute to enhancing the learning experiences of students, this set is intended to be used holistically as an overall design in which the principles complement each other. This creates a better representation of the current concepts of sustainability learning and transdisciplinary and transformative sustainability research.

Although the principles address and encompass the content, organisation, and didactics of higher education sustainability learning through transformative learning and transformative research, they do not tackle the fundamental aspects concerning the need to embed such modules and programmes in higher education institutions. A chapter in the handbook does focus on aspects to be aware of when integrating such modules into study programmes (Wanner et al., 2020, p. 52), including the selection of an appropriate study programme, the importance of considering semester schedules and study programme structures, as well as examination requirements, group sizes, and the promotion of the course. However, local educational actors must meet the challenge of how to ensure that there is both the will and adequate resources to embed such modules into higher education institutions. This action must happen from the top down by ambitious academic leaders in higher education institutions via mission statements, changes to institutional structure and resource allocation, and from the bottom up by engaged academic staff who choose to develop and lead suitable educational programmes.

5.2 Challenges for teaching

As suggested in the literature, teaching sustainability learning-oriented courses necessitates novel understandings around modes of collaboration and engagement with students. Creating safe environments for students to learn in a self-directed way and to explore sustainability problems with practitioners demands a high degree of support from course leaders. While teaching in the TIL, we found ourselves covering a wide range of activities, such as providing input, practical guidance, emotional and psychological support, managing contact with practice partners, organising peer learning encounters outside the university, and supervising Masters theses. In a similar way in which researchers adopt diverse roles in transdisciplinary settings (Wittmayer & Schäpke, 2014), course leaders are forced to adopt

wide-ranging roles that in many ways transcend the traditional understanding of teaching in higher education (namely that of passing on knowledge).

We therefore advise that further investigation should be carried out into the necessary roles and competencies of lecturers in these contexts. Moreover, we encourage lecturers in this field to further connect, mutually reflect on their experiences, and establish support networks across institutions where they can jointly address the challenges they encounter in their practice. This would be especially valuable for early-career researchers at universities who are often highly motivated to teach demanding real-world focussed courses but are ultimately often left alone to experience learning-by-doing. In addition, such options for exchange could and would facilitate interdisciplinary exchange locally and (inter-) nationally. In universities that are still structured according to the different disciplines, interdisciplinarity—as a basis for transdisciplinary projects—is particularly hard to achieve in single study programmes.

A specific issue to be aware of is the potential for the students to experience emotionally challenging and individually disorienting dilemmas. Transformative learning as an approach that encompasses profound individual reflection ideally calls for demanding situations in order to open a window for questioning personal perspectives and transforming problematic frames of reference. Although this approach seems rational and effective, it is difficult to manage. Inviting students to create their own learning environment and journey is not a sure-fire method of inducing a disorienting dilemma—and if such a dilemma is induced, this can raise psychological and ethical questions. Accordingly, the challenge is to provide students with sufficient incentives and a safe space that enables them to create a situation that is individually challenging but not overwhelming.

5.3 Universities as drivers for experimental urban and regional transformations

As stated in introduction, the world needs scaled and accelerated transformation processes towards sustainable development. Universities as relevant hubs for innovation, modern higher education, and regional development play an important role in urban and regional development. At stake is the role of universities as drivers for a new, co-creative, and sustainability-oriented transfer and third mission (Evans et al., 2015; Karvonen & van Heur, 2014; Schneidewind, 2020; Trencher et al., 2014). The complex cycle of technical innovation through to market launch was thoroughly and effectively developed in the twentieth century, but the greatest task currently facing the world is to ideologically divest from fossil fuels and other unsustainable industries and technologies and focus on clean, future-proof innovation. In the realm of social innovation, we still need a similarly developed complex of mechanisms for producing socially robust knowledge between universities and society. If universities want to play an influential role in this sphere—which they should—they must develop widely institutionalised, thematically differentiated, and socially effective means of teaching and researching (see also König, 2013). The various approaches already mentioned in this paper (urban or sustainable living laboratories, urban transition laboratories, real-world laboratories, or similar) illustrate the multi-faceted search for adequate research formats for such a sustainable and socially robust third mission. We assert that developing a variety of learning options at every university, based on the principles we have set out, would be an important and necessary step towards fruitful teaching formats. Taken together, transformative research formats, transformative teaching offerings, and the associated necessary institutional changes would fulfil the idea of an encompassing

transformative science (Schneidewind et al., 2016). The principles outlined in this paper aim to contribute to this discourse and to institutional change.

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Declarations

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References

- Barth, M., Adomßent, M., Fischer, D., Richter, S., & Rieckmann, M. (2014). Learning to change universities from within: A service-learning perspective on promoting sustainable consumption in higher education. *Journal of Cleaner Production*, 62, 72–81. <https://doi.org/10.1016/j.jclepro.2013.04.006>
- Barth, M. (2016). *Implementing sustainability in higher education: Learning in an age of transformation*. Routledge.
- Bergmann, M., Schäpke, N., Marg, O., Stelzer, F., Lang, D. J., Bossert, M., Gantert, M., Häußler, E., Marquardt, E., Piontek, F. M., Potthast, T., Rhodius, R., Rudolph, M., Ruddat, M., Seebacher, A., & Sußmann, N. (2021). Transdisciplinary sustainability research in real-world labs: Success factors and methods for change. *Sustainability Science*. <https://doi.org/10.1007/s11625-020-00886-8>
- Bergmann, M., Brohmann, B., Hoffmann, E., Loibl, M. C., Rehaag, R., Schramm, E., & Voß, J.-P. (2005). *Quality Criteria of Transdisciplinary Research. A Guide for the Formative Evaluation of Research Projects*. Institut für sozial-ökologische Forschung (ISOE). <http://www.isoe.de>
- Brookfield, S. D. (2000). Transformative learning as ideology critique. In J. Mezirow (Ed.), *Learning as transformation: Critical perspectives on a theory in progress* (pp. 125–148). USA: Jossey-Bass.
- Brundiers, K., & Wiek, A. (2013). Do we teach what we preach? An international comparison of problem- and project-based learning courses in sustainability. *Sustainability*, 5(4), 1725–1746. <https://doi.org/10.3390/su5041725>
- Brundiers, K., Barth, M., Cebrián, G., Cohen, M., Diaz, L., Doucette-Remington, S., Dripps, W., Habron, G., Harré, N., Jarchow, M., Losch, K., Michel, J., Mochizuki, Y., Rieckmann, M., Parnell, R., Walker, P., & Zint, M. (2021). Key competencies in sustainability in higher education—Toward an agreed-upon reference framework. *Sustainability Science*, 16(1), 13–29. <https://doi.org/10.1007/s11625-020-00838-2>

- Caniglia, G., Schöpke, N., Lang, D. J., Abson, D. J., Luederitz, C., Wiek, A., Laubichler, M. D., Gralla, F., & von Wehrden, H. (2017). Experiments and evidence in sustainability science: A typology. *Journal of Cleaner Production*, 169, 39–47. <https://doi.org/10.1016/j.jclepro.2017.05.164>
- Caniglia, G., Luederitz, C., von Wirth, T., Fazey, I., Martín-López, B., Hondrita, K., König, A., von Wehrden, H., Schöpke, N. A., Laubichler, M. D., & Lang, D. J. (2020). A pluralistic and integrated approach to action-oriented knowledge for sustainability. *Nature Sustainability*. <https://doi.org/10.1038/s41893-020-00616-z>
- Cörvers, R., Wiek, A., de Kraker, J., Lang, D. J., & Martens, P. (2016). Problem-Based and Project-Based Learning for Sustainable Development. In H. Heinrichs, P. Martens, G. Michelsen, & A. Wiek (Eds.), *Sustainability Science* (pp. 349–358). Netherlands: Springer.
- Cranton, P., & King, K. P. (2003). Transformative Learning as a Professional Development Goal. *New Directions for Adult and Continuing Education*, 2003(98), 31–38. <https://doi.org/10.1002/ace.97>
- Dabaieh, M., El Mahdy, D., & Maguid, D. (2018). Living Labs as a Pedagogical Teaching Tool for Green Building Design and Construction in Hot Arid Regions. *International Journal of Architectural Research: Archnet-IJAR*, 12(1), 338. <https://doi.org/10.26687/archnet-ijar.v12i1.1285>
- Dale, A., & Newman, L. (2005). Sustainable development, education and literacy. *International Journal of Sustainability in Higher Education*, 6(4), 351–362. <https://doi.org/10.1108/14676370510623847>
- de Haan, G. (2008). Gestaltungskompetenz als Kompetenzkonzept der Bildung für nachhaltige Entwicklung. In I. Bormann & G. de Haan (Eds.), *Kompetenzen der Bildung für nachhaltige Entwicklung* (pp. 23–43). VS Verlag für Sozialwissenschaften. https://doi.org/10.1007/978-3-531-90832-8_4
- Evans, J., Jones, R., Karvonen, A., Millard, L., & Wendler, J. (2015). Living labs and co-production: University campuses as platforms for sustainability science. *Current Opinion in Environmental Sustainability*, 16, 1–6. <https://doi.org/10.1016/j.cosust.2015.06.005>
- Foley, R., Wiek, A., & Kay, B. (2017). Nanotechnology Development as if People and Places Matter. *Nano-Ethics*, 11(3), 243–257. <https://doi.org/10.1007/s11569-017-0300-y>
- Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Peter, S., & Trow, M. (1994). *The new production of knowledge: The dynamics of science and research in contemporary societies*. UK: Sage.
- Grunwald, A., & Kopfmüller, J. (2012). *Nachhaltigkeit: Eine Einführung*. Germany: Campus Verlag.
- Hirsch Hadorn, G., Bradley, D., Pohl, C., Rist, S., & Wiesmann, U. (2006). Implications of transdisciplinarity for sustainability research. *Ecological Economics*, 60(1), 119–128. <https://doi.org/10.1016/j.ecolecon.2005.12.002>
- Jahn, T., Bergmann, M., & Keil, F. (2012). Transdisciplinarity: Between mainstreaming and marginalization. *Ecological Economics*, 79, 1–10. <https://doi.org/10.1016/j.ecolecon.2012.04.017>
- Karvonen, A., & van Heur, B. (2014). Urban Laboratories: Experiments in reworking cities: Introduction. *International Journal of Urban and Regional Research*, 38(2), 379–392. <https://doi.org/10.1111/1468-2427.12075>
- Kemmis, S., & McTaggart, R. (2000). Participatory action research. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research*. UK: Sage Publications.
- Kemp, R., Schot, J., & Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. *Technology Analysis & Strategic Management*, 10(2), 175–198. <https://doi.org/10.1080/09537329808524310>
- Kemp, R., Loorbach, D., & Rotmans, J. (2007). Transition management as a model for managing processes of co-evolution towards sustainable development. *International Journal of Sustainable Development & World Ecology*, 14(1), 78–91. <https://doi.org/10.1080/13504500709469709>
- Klein, J. T. (2006). Resources for Interdisciplinary Studies. *Change the Magazine of Higher Learning*, 38(2), 50–56. <https://doi.org/10.3200/CHNG.38.2.50-56>
- König, A. (2013). *Regenerative Sustainable Development of Universities and Cities*. Edward Elgar Publishing. <https://doi.org/10.4337/9781781003640>
- Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., & Thomas, C. J. (2012). Transdisciplinary research in sustainability science: Practice, principles, and challenges. *Sustainability Science*, 7(S1), 25–43. <https://doi.org/10.1007/s11625-011-0149-x>
- Lange, E. A. (2012). Transforming Transformative Learning Through Sustainability and the New Science. In E. W. Taylor & P. Cranton (Eds.), *The handbook of transformative learning: Theory, research, and practice* (1st ed., pp. 195–211). USA: Jossey-Bass.
- Larsson, J., & Holmberg, J. (2018). Learning while creating value for sustainability transitions: The case of Challenge Lab at Chalmers University of Technology. *Journal of Cleaner Production*, 172, 4411–4420. <https://doi.org/10.1016/j.jclepro.2017.03.072>
- Liedtke, C., Baedeker, C., Hasselkuß, M., Rohn, H., & Grinewitschus, V. (2015). User-integrated innovation in Sustainable LivingLabs: An experimental infrastructure for researching and developing sustainable product service systems. *Journal of Cleaner Production*, 97, 106–116.


- Luederitz, C., Schäpke, N., Wiek, A., Lang, D. J., Bergmann, M., Bos, J. J., Burch, S., Davies, A., Evans, J., König, A., Farrelly, M. A., Forrest, N., Frantzeskaki, N., Gibson, R. B., Kay, B., Loorbach, D., McCormick, K., Parodi, O., Rauschmayer, F., ... Westley, F. R. (2017). Learning through evaluation – A tentative evaluative scheme for sustainability transition experiments. *Journal of Cleaner Production*, 169, 61–76. <https://doi.org/10.1016/j.jclepro.2016.09.005>
- Mauser, W., Klepper, G., Rice, M., Schmalzbauer, B. S., Hackmann, H., Leemans, R., & Moore, H. (2013). Transdisciplinary Global Change Research: The Co-creation of Knowledge for Sustainability. *Current Opinion in Environmental Sustainability*, 5(3–4), 420–431. <https://doi.org/10.1016/j.cosust.2013.07.001>
- McCrory, G., Schäpke, N., Holmén, J., & Holmberg, J. (2020). Sustainability-oriented labs in real-world contexts: An exploratory review. *Journal of Cleaner Production*, 277, 123202. <https://doi.org/10.1016/j.jclepro.2020.123202>
- Mezirow, J. (1991). *Transformative dimensions of adult learning* (1st ed.). USA: Jossey-Bass
- Mezirow, J. (1997). Transformative Learning: Theory to Practice. *New Directions for Adult and Continuing Education*, 1997(74), 5–12. <https://doi.org/10.1002/ace.7401>
- Mezirow, J. (2003). Transformative Learning as Discourse. *Journal of Transformative Education*, 1(1), 58–63. <https://doi.org/10.1177/1541344603252172>
- Nevens, F., Frantzeskaki, N., Gorissen, L., & Loorbach, D. (2013). Urban Transition Labs: Co-creating transformative action for sustainable cities. *Journal of Cleaner Production*, 50, 111–122. <https://doi.org/10.1016/j.jclepro.2012.12.001>
- Nowotny, H., Scott, P., & Gibbons, M. (2001). *Re-thinking science: Knowledge and the public in an age of uncertainty*. UK: Polity Press.
- Overdevest, C., Bleicher, A., & Gross, M. (2010). The Experimental Turn in Environmental Sociology: Pragmatism and New Forms of Governance. In M. Gross & H. Heinrichs (Eds.), *Environmental Sociology* (pp. 279–294). Netherlands: Springer.
- Ozanne, J. L., & Saatcioglu, B. (2008). Participatory Action Research. *Journal of Consumer Research*, 35(3), 423–439. <https://doi.org/10.1086/586911>
- Parodi, O., Waitz, C., Bachinger, M., Kuhn, R., Meyer-Soylu, S., Alcántara, S., & Rhodius, R. (2018). Insights into and recommendations from three real-world laboratories: An experience-based comparison. *GAIA - Ecological Perspectives for Science and Society*, 27(1), 52–59. <https://doi.org/10.14512/GAIA.27.S1.12>
- Pereira, L., Drimie, S., Zgambo, O., & Biggs, R. (2020). Planning for change: Transformation labs for an alternative food system in Cape Town South Africa. *Urban Transformations*, 2(1), 13. <https://doi.org/10.1186/s42854-020-00016-8>
- Pfau, N., & Uhl, E. (2021). *B: Inter- and transdisciplinary teaching and learning within the Reallabor (Real-World Laboratory for Sustainable Mobility Culture)*. Stuttgart : Reallabor für nachhaltige Mobilitätskultur - Future City Lab. Stuttgart. <https://doi.org/10.18419/opus-11756>
- Pohl, C., Krütli, P., & Stauffacher, M. (2018). Teaching Transdisciplinarity Appropriately for Students' Education Level. *GAIA - Ecological Perspectives for Science and Society*, 27(2), 250–252. <https://doi.org/10.14512/gaia.27.2.14>
- Rieckmann, M. (2012). Future-oriented higher education: Which key competencies should be fostered through university teaching and learning? *Futures*, 44(2), 127–135. <https://doi.org/10.1016/j.futures.2011.09.005>
- Rodríguez Aboytes, J. G., & Barth, M. (2020). Transformative learning in the field of sustainability: A systematic literature review (1999–2019). *International Journal of Sustainability in Higher Education*, 21(5), 993–1013. <https://doi.org/10.1108/IJSHE-05-2019-0168>
- Rowe, D. (2007). Sustainability: Education for a Sustainable Future. *Science*, 317(5836), 323–324. <https://doi.org/10.1126/science.1143552>
- Schneidewind, U. (2014). Urbane Reallabore – ein Blick in die aktuelle Forschungswerkstatt. *Pnd Online*, 3, 1–7.
- Schneidewind, U., Singer-Brodowski, M., Augenstein, K., & Stelzer, F. (2016). *Pledge for a transformative science: A conceptual framework*. Wuppertal papers. <http://nbn-resolving.de/urn:nbn:de:bsz:wup4-opus-64142>
- Schneidewind, U. (2020). *Hochschulen nach Corona – der urbane Campus als neues Organisationsprinzip von Lehre und Forschung?*. Merton. <https://merton-magazin.de/hochschulen-nach-corona-der-urbane-campus-als-neues-organisationsprinzip-von-lehre-und-forschung>. retrieved on Dec 16, 2022
- Scholz, R. W., Lang, D. J., Wiek, A., Walter, A. I., & Stauffacher, M. (2006). Transdisciplinary case studies as a means of sustainability learning: Historical framework and theory. *International*

- Journal of Sustainability in Higher Education*, 7(3), 226–251. <https://doi.org/10.1108/14676370610677829>
- Singer-Brodowski, M., Beecroft, R., & Parodi, O. (2018). Learning in Real-World Laboratories: A Systematic Impulse for Discussion. *GAIA - Ecological Perspectives for Science and Society*, 27(1), 23–27. <https://doi.org/10.14512/gaia.27.S1.7>
- Singer-Brodowski, M. (2016a). Transformative Bildung durch transformatives Lernen Zur Notwendigkeit der erziehungswissenschaftlichen Fundierung einer neuen Idee. *ZEP Zeitschrift Für Internationale Bildungsforschung Und Entwicklungspädagogik*, 39(1), 13–17. <https://doi.org/10.25656/01:15443>
- Singer-Brodowski, M. (2016b). Transformatives Lernen als neue Theorie-Perspektive in der BNE. *Im Wandel - Jahrbuch Bildung für nachhaltige Entwicklung*. Umweltdachverband GmbH. Vienna.
- Stauffacher, M., Walter, A. I., Lang, D. J., Wiek, A., & Scholz, R. W. (2006). Learning to research environmental problems from a functional socio-cultural constructivism perspective: The transdisciplinary case study approach. *International Journal of Sustainability in Higher Education*, 7(3), 252–275. <https://doi.org/10.1108/14676370610677838>
- Sterling, S., Glasser, H., Rieckmann, M., & Warwick, P. (2017). 10. “More than scaling up”: A critical and practical inquiry into operationalizing sustainability competencies. In P. B. Corcoran, J. P. Weakland, & A. E. J. Wals (Eds.), *Envisioning futures for environmental and sustainability education* (pp. 153–168). Wageningen Academic Publishers. https://doi.org/10.3920/978-90-8686-846-9_10
- Sterling, S., & Thomas, I. (2006). Education for sustainability: The role of capabilities in guiding university curricula. *International Journal of Innovation and Sustainable Development*, 1(4), 349. <https://doi.org/10.1504/IJISD.2006.013735>
- Tejedor, G., Segalàs, J., Barrón, Á., Fernández-Morilla, M., Fuertes, M., Ruiz-Morales, J., Gutiérrez, I., García-González, E., Aramburuzabala, P., & Hernández, Á. (2019). Didactic strategies to promote competencies in sustainability. *Sustainability*, 11(7), 2086. <https://doi.org/10.3390/su11072086>
- Stibbe, A. (Ed.). (2009). *The handbook of sustainability literacy: Skills for a changing world*. UK: Green.
- Trencher, G., Yarime, M., McCormick, K. B., Doll, C. N. H., & Kraines, S. B. (2014). Beyond the third mission: Exploring the emerging university function of co-creation for sustainability. *Science and Public Policy*, 41(2), 151–179. <https://doi.org/10.1093/scipol/sct044>
- UN - United Nations. (2015). *Resolution adopted by the General Assembly on 25 September 2015 (A/RES/70/1; Transforming Our World: The 2030 Agenda for Sustainable Development)*. United Nations. <https://undocs.org/en/A/RES/70/1>
- UNESCO. (2005). *United Nations Decade of Education for Sustainable Development (2005–2014): International Implementation Scheme (ED/DESD/2005/PI/01)*.
- Voytenko, Y., McCormick, K., Evans, J., & Schliwa, G. (2016). Urban living labs for sustainability and low carbon cities in Europe: Towards a research agenda. *Journal of Cleaner Production*, 123, 45–54. <https://doi.org/10.1016/j.jclepro.2015.08.053>
- Wanner, M., Hilger, A., Westerkowski, J., Rose, M., Stelzer, F., & Schäpke, N. (2018). Towards a Cyclical Concept of Real-world Laboratories: A Transdisciplinary Research Practice for Sustainability Transitions. *DisP - the Planning Review*, 54(2), 94–114. <https://doi.org/10.1080/02513625.2018.1487651>
- Wanner, M., Schmitt, M., Fischer, N., & Bernert, P. (2020). *Transformative Innovation Lab Handbook to facilitate student's real-world laboratory projects to promote transformative and transdisciplinary competencies*. Wuppertal Institut.
- Wanner, M., Bernert, P., Fischer, N., & Schmitt, M. (2021a). Creación de espacios de aprendizaje y enseñanza para la investigación transformadora y transdisciplinar: El Laboratorio de Innovación Transformadora. *DIDAC*, 78 JUL-DIC, 60–71. https://doi.org/10.48102/didac.2021..78_JUL-DIC.80
- Wanner, M., Bernert, P., Fischer, N., & Schmitt, M. (2021b). Creating Learning and Teaching Spaces for Transformative and Transdisciplinary Research: The Transformative Innovation Lab. *DIDAC*, 78 JUL-DIC, 49–59. https://doi.org/10.48102/didac.2021..78_JUL-DIC.83
- WBGU - German Advisory Council on Global Change. (2011). *World in Transition – A Social Contract for Sustainability*. Wiss. Beirat d. Bundesregierung Globale Umweltveränderungen. <https://www.wbgu.de/en/publications/publication/world-in-transition-a-social-contract-for-sustainability>
- Weiss, M., & Barth, M. (2019). Global research landscape of sustainability curricula implementation in higher education. *International Journal of Sustainability in Higher Education*, 20(4), 570–589. <https://doi.org/10.1108/IJSHE-10-2018-0190>
- Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability: A reference framework for academic program development. *Sustainability Science*, 6(2), 203–218. <https://doi.org/10.1007/S11625-011-0132-6>

Wittmayer, J., & Schäpke, N. (2014). Action, research and participation: Roles of researchers in sustainability transitions. *Sustainability Science*, 9(4), 483–496. <https://doi.org/10.1007/s11625-014-0258-4>

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