

Utilizing international networks for accelerating research and learning in transformational sustainability science

Lauren Withycombe Keeler¹ · Arnim Wiek^{1,2} · Daniel J. Lang¹ · Makoto Yokohari³ · John van Breda⁴ · Lennart Olsson⁵ · Barry Ness⁵ · Jordi Morato⁶ · Jordi Segalàs⁶ · Pim Martens⁷ · Luis A. Bojórquez-Tapia⁸ · James Evans⁹

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Abstract A promising approach for addressing sustainability problems is to recognize the unique conditions of a particular place, such as problem features and solution capabilities, and adopt and adapt solutions developed at other places around the world. Therefore, research and teaching in *international networks* becomes critical, as it allows for accelerating learning by sharing problem understandings, successful solutions, and important contextual considerations. This article identifies eight distinct types of research and teaching collaborations in international networks that can support such accelerated learning. The four research types are, with increasing intensity of collaboration: (1) solution adoption; (2) solution consultation; (3) joint research on different problems; and (4) joint research on similar problems. The four teaching types are, with increasing intensity of collaboration: (1) adopted course; (2) course with visiting faculty; (3) joint course with traveling faculty; and (4) joint course with traveling

students. The typology is illustrated by extending existing research and teaching projects on urban sustainability in the International Network of Programs in Sustainability, with partner universities from Europe, North America, Asia, and Africa. The article concludes with challenges and strategies for extending individual projects into collaborations in international networks.

Keywords Sustainability science · Sustainability education · International networks · University collaborations

Introduction

Individuals, society, and ecosystems suffer the negative effects of climate change, freshwater scarcity and contamination, improper and increasing waste disposal, inequitable access to healthy food, rising education and healthcare costs, new infectious diseases and transmission

Handled by Osamu Saito, United Nations University Institute for the Advanced Study of Sustainability (UNU-IAS), Japan.

✉ Lauren Withycombe Keeler
lauren.withycombe@asu.edu

¹ Faculty of Sustainability, Leuphana University of Lüneburg, 21335 Lunenburg, Germany

² School of Sustainability, Arizona State University, Tempe, AZ 85287-5502, USA

³ Department of Urban Engineering, Graduate School of Engineering, The University of Tokyo, Hongo, Tokyo 113-8656, Japan

⁴ School of Public Leadership, Stellenbosch University, Matieland, Stellenbosch 7602, South Africa

⁵ Lund University Centre for Sustainability Studies (LUCSUS), Lund University, 221 00 Lund, Sweden

⁶ Research Institute for Sustainability Science and Technology, Universitat Politècnica de Catalunya, 08034 Barcelona, Spain

⁷ International Center for Integrated Assessment and Sustainable Development (ICIS), Maastricht University, MD 6200 Maastricht, The Netherlands

⁸ Laboratorio Nacional de Ciencias de la Sostenibilidad (LANCIS), Instituto de Ecología, Universidad Nacional Autónoma de México (UNAM), Ciudad Universitaria, Mexico, DF, Mexico

⁹ School of Environment, Education and Development, University of Manchester, Manchester M13 9PL, UK

pathways, wars and violent conflicts, and other harmful long-term challenges, i.e., sustainability challenges. Despite examples of innovative local solutions to these problems, society still has to significantly increase and connect efforts to avoid irreversible harm (Rockström et al. 2009). The urgency of these problems demands *accelerating* learning across society and nations. Transformational sustainability science, following this call, employs innovative models to better facilitate *learning together* and *learning from each other* in finding solutions to sustainability challenges (Wiek et al. 2012, 2015). Transformational sustainability science is positioned in line with the post-normal science paradigm, which addresses complex, urgent, and societally relevant problems (Funtowicz and Ravetz 1993). It departs from sustainability science as outlined by (Kates et al. 2001) that calls for descriptive-analytical knowledge on origin, structure, and functioning of sustainability problems to advance understanding of resilience and vulnerability in social-ecological systems. In transformational sustainability science, actionable knowledge is generated on solutions that alleviate the symptoms or change the underlying causal structures of sustainability problems (Wiek et al. 2012; Brundiers et al. 2013). To achieve these objectives, universities are increasingly engaged in multistakeholder, transdisciplinary efforts to catalyze sustainability transformation (Lang and Wiek 2013; Trencher et al. 2014a). This often necessitates creating transdisciplinary “learning networks” which enable knowledge co-production between knowledge producers and users (Talwar et al. 2011; Valkering et al. 2013; cf. Downes 2007). Such learning networks can be extended to international university collaborations where knowledge on sustainability research and education is transferred as well as co-produced between partner institutions.

This article systematically explores how international networks can accelerate research and learning on solutions to urgent sustainability problems. A number of universities have taken up the call to collaborate internationally for sustainability. There is a need, however, to explore how these partnerships could be structured to maximize their transformational impact for sustainability. To build an empirically informed concept of international university collaboration in research and education *for sustainability transformation* we draw from the existing literature. We illustrate recommended collaborative models with research and teaching projects from partner universities in the International Network of Programs in Sustainability (NEPS). The majority of these projects have been conceived or conducted as projects at only *one* university. They have or are about to generate impactful outputs and outcomes. Yet, they still have an untapped potential for broader impact when extended through international collaboration. Building on insights from 8 years of

collaboration within NEPS, we explore the different ways these exemplary projects can be extended into international collaborations in a way that might accelerate the transformational impact of sustainability science. NEPS is used here as an exemplary network as it is committed to enhancing *international collaboration on solution-oriented sustainability research and teaching*. NEPS includes leading sustainability programs from the following universities: Arizona State University (ASU), USA; Leuphana University of Lüneburg (LUL), Germany; Lund University, Sweden; Maastricht University, the Netherlands; Stellenbosch University (STB), South Africa; Universidad Nacional Autónoma de México (UNAM), Mexico; Universitat Politècnica de Catalunya (UPC), Spain; and the University of Tokyo (UT), Japan.

Universities can play an instrumental role in the sustainability transformation of cities and regions (Crow 2010; König and Evans 2013; Lang and Wiek 2013; Trencher et al. 2014a; Wiek and Kay 2015). Universities can do this by taking up campus-wide sustainability practices (Koester et al. 2006; Cayuela et al. 2013) or by orienting research and education toward the surrounding community (Savan and Sider 2003; Brundiers et al. 2010; Trencher et al. 2014a; Wiek et al. 2016). The literature, however, does not provide clear insights on how international partnerships can lead to or even accelerate positive local impact. While some studies have reviewed numerous university stakeholder collaborations for sustainability (e.g., Trencher et al. 2014a, b; Zilahy and Huisingh 2009), a typology of differing types of collaborations is still absent from the literature. This article offers illustrated insights on how international networks can be utilized to coordinate: (1) research to guide sustainability transformations forward through generalizable knowledge on sustainability problems as well as solutions and strategies for their adaption to concrete local contexts, and (2) teaching to educate future change agents with cross-cultural competence in solving sustainability problems. We conclude with a discussion of strategies for developing individual projects into collaborations in international networks that can accelerate sustainability research and learning.

Sustainability projects at partner universities of NEPS

The partner universities of NEPS have conceived and conducted a variety of research and teaching projects on urban sustainability around the world, from which we have selected and described an exemplary set in Table 1. Projects were selected from each NEPS university for their alignment with the goals of transformational sustainability science, their place-based nature, and their potential for

Table 1 Profiles of projects on urban sustainability at partner universities of NEPS

	Universitat Politècnica de Catalunya	Maastricht University	Stellenbosch University	Universidad Nacional Autónoma de México
(1) Background				
Project name	The Environmental Restoration Plan of the Morro de Moravia, in Medellín, Colombia	Urban Experiments with Living Labs & City Labs (URB@Exp)	Re-imagining and Co-Designing the Future of Stellenbosch: Towards a TOD Approach	Megadapt
Location(s)	Medellín, Colombia	Maastricht, Netherlands	Stellenbosch, South Africa	Mexico City, Mexico
Time frame	2008–2012	2014–present	2010–present	2014–present
Lead organization	UNESCO Chair on Sustainability from the Universitat Politècnica de Catalunya (UPC)	International Center for Integrated Assessment and Sustainable Development (ICIS)	School of Public Leadership	Laboratorio Nacional de las Ciencias de la Sostenibilidad (LANCIS)
Main external partner(s)	Medellín City Administration Residents of Moravia	City administration	Municipality of Stellenbosch	Mexico City public officials
Problem	Leakage of polluted effluent from municipal landfill into informal settlements	Unsustainable governance of cities	Sprawled development, inequality and limited transportation access	Flooding of contaminated wastewater during storms
Foci	(1) Research and implementation	(1) Research and implementation	(2) Research and planning	(2) Research and planning
(2) Outputs				
Sustainable development goals	Sustainable cities and human settlements, waste and sanitation	Governance	Sustainable transport	Water and sanitation, sustainable cities and human settlements
Knowledge produced	Best available technology solution	Current state, visions, interventions, evaluations	Current state, visions, scenarios, strategies	Current state, scenarios
Capacity built	Interpersonal, strategic and problem-solving competence	Systems thinking, normative and problem-solving competence	Anticipatory, strategic and interpersonal competence	Systems thinking, anticipatory and interpersonal competence
Real-world changes	New infrastructure, new livelihood, new social network	Urban labs in cities, new professional relationships, new rules, new urban development	Changed values, rules, new professional relationships	New professional relationships, changed perspectives
(3) Outcomes				
Sustainability achieved	Livelihood opportunity	Not yet	Not yet	Not yet
(4) Process				
Methods	SES integrity Intra-/inter-generational equity Participation Current state analysis, strategy/solution development, implementation	Current state analysis, visioning, intervention design, implementation, evaluation	Current state analysis, visioning, scenarios, strategy development	Current state analysis
Stakeholder engagement	Information, collaboration, empowerment	Consultation, collaboration	Information, collaboration and empowerment	Collaboration
Student engagement	Research assistants	Research assistants, M.A. thesis projects	Research assistants	None

Table 1 continued

	Universitat Politècnica de Catalunya	Maastricht University	Stellenbosch University	Universidad Nacional Autónoma de México
(5) Exemplary collaboration				
Research	(1) Solution adoption Barcelona → UPC → UT	(2) Solution consultation Maastricht → UNAM	(1) Solution adoption ASU → STB	(3) Joint research dif. problem UT ↔ UNAM
Teaching	(1) Adopted course STB → UPC	(2) Course w/ visiting faculty Maastricht → ASU	(1) Adopted course STB → UPC	(4) Joint course travel. stud UT ↔ UNAM
(6) Website	http://www.unecosost.org/en/project/moravia-florece-para-la-vida/	http://shapingstellenbosch.co.za/?page_id=186	http://shapingstellenbosch.co.za/?page_id=186	
	University of Tokyo	Leuphana University	Arizona State University	Lund University
(1) Background				
Project name	Sustainable Urban Fringe Landscapes in Bangkok	Buy Local Initiative Lüneburg	Revitalizing Public Spaces for the Public Good	Knowledge to Action for Sustainable Development—The Case of Coffee Production, Distribution, and Consumption
Location(s)	2013 Bang Krachao, Thailand	2015–2016 Lüneburg, Germany	2013–2014 Phoenix, Arizona	2014 Lund, Sweden
Lead organization	Graduate School of Frontier Sciences	Institute of Ethics and Transdisciplinary Sustainability Research	Sustainability Transition and Intervention Research Lab	Lund University Centre for Sustainability Studies (LUCSUS)
Main external partner(s)		Lüneburg Buy Local Network, Local First Arizona	Crockett Elementary School, Balsz School District, Maricopa County Department of Public Health, CoP Neighbor. Serv. Depart	Local coffee shop owner
Problem	Lack of food security in areas prone to environmental disasters	Local businesses struggling with global trade; Unsustainable cities and local economies	Lack of public space and access to fresh food	Unsustainable coffee supply chains
Foci	(3) Teaching and planning	(3) Teaching and planning	(4) Teaching and implementation	(4) Teaching and implementation

Table 1 continued

	University of Tokyo	Leuphana University	Arizona State University	Lund University
(2) Outputs				
Sustainable development goals	Climate Change and Disaster Reduction, Sustainable Agriculture	Sustainable Consumption and Production, Sustainable Cities and Human Settlements	Sustainable Cities and Human Settlements, Sustainable Agriculture	Sustainable Consumption and Production; Inclusive and Sustainable Economic Growth
Knowledge produced	System model, visions	System model, scenarios, assessment, interventions	System models, visions, strategies	System model, interventions
Capacity built	Systems thinking, normative and cross-cultural (interpersonal) competence	Systems thinking, anticipatory, strategic and problem-solving competence	Systems thinking, anticipatory, strategic, interpersonal, and problem-solving competence	Systems thinking, strategic and problem-solving competence
Real-world changes	Changed student perspectives	Raised awareness, new/expanded prof. network; new products/services	Changed values, rules; new infrastructures; professional relationships	New relationship between coffee producers and sellers
(3) Outcomes				
Sustainability achieved	No	Not yet	Improvements: SES integrity Intra-/inter-generational equity Participation	Livelihood sufficiency Participation
(4) Process				
Methods	Current state analysis, visioning	Current state analysis, scenario development, assessment, intervention design, implementation Collaboration	Current state analysis, visioning, intervention design, implementation	Current state analysis, intervention design, implementation
Stakeholder engagement	Information, consultation Graduate student course	Collaboration Graduate student course	Collaboration, empowerment Undergraduate student course	Consultation, collaboration Graduate student course
Student engagement	Graduate student course	Graduate student course	Undergraduate student course	Graduate student course

Table 1 continued

	University of Tokyo	Leuphana University	Arizona State University	Lund University
(5) Exemplary collaboration Research	(3) Joint research dif. problem UT ↔ UNAM (4) Joint course travel. stud UT ↔ UNAM http://www.envleader.u-tokyo.ac.jp/field/?docs=sustainable-urban-fringe-landscapes-in-bangkok-thailand-2	(4) Joint research sim. problem ASU ↔ LUL (3) Joint course travel. faculty Lund ↔ LUL http://www.leuphana.de/en/institute/etsr/forschung-projekte/arbeitsgruppe-local-living-economies-buy-local.html	(4) Joint research sim. problem ASU ↔ LUL (4) Joint course travel. students ASU ↔ LUL https://cbs.asu.edu/global-classroom%E2%80%9C-sustainable-cities-contradiction-terms%E2%80%9D	(2) Solution consultation Lund → LUL (3) Joint course travel. faculty Lund ↔ LUL
Teaching				
(6) Website				

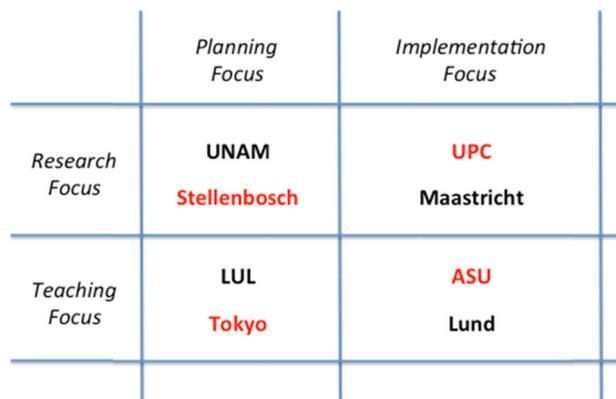


Fig. 1 Classification of projects on urban sustainability at NEPS partner universities, according to their respective foci; highlighted are the projects that are describe in more detail below

expanded impact through international collaboration in either research or teaching. The framework employed to analyze, evaluate and compare the projects was adopted from similar evaluative studies (Forrest and Wiek 2014; Wiek et al. 2016). The analytical-evaluative framework provides relevant background information for comparison purposes and focuses explicitly on the process, outputs, and outcomes of the projects. Outputs are conceptualized as immediate results of research, whereas outcomes are conceived as achievement of sustainability goals.

Figure 1 maps these projects onto two important axes; namely, whether they focus on (1) *planning or implementation*; and whether they focus on (2) *research or teaching*. While all projects are intended to develop solution options to sustainability problems, they differ with respect to their ‘reach’. On the one hand, this refers to whether they concluded with an action plan (planning focus), or with the actual implementation of such a plan, plus evaluation (implementation focus). This axis reflects the extension of sustainability research towards transformation beyond the “normal” role of knowledge brokerage (Reeger and Bunders 2009). On the other hand, this refers to whether the projects focused on generating outputs and outcomes (research focus), or rather on building capacity in students (teaching focus). Sustainability projects increasingly include elements of both in the form of research-led teaching and teaching-led research. For example, graduate students are supported in conducting their dissertations within existing research projects, and courses use problem- and project-based learning formats to engage students in research. While most projects simultaneously pursue several objectives, we highlight here the projects’ *main* focus on each axis.

Four projects that exemplify the breadth of processes, outputs, and outcomes are described in more detailed vignettes below. One exemplary project was selected from

each quadrant along the planning and implementation, and research and teaching axes (Fig. 1). They are discussed along the key features of the analytical-evaluative framework to provide case specific details to the standardized and comparable information provided in Table 1.

Universitat Politècnica de Catalunya (UPC): research focus and implementation focus

Researchers from UPC worked on the project *The Environmental Restoration Plan of the Morro de Moravia* from 2008 to 2012 with numerous municipal and community partners in Medellín, Colombia (Morató et al. 2011; Montoya et al. 2011; ANSPE 2013; Morató 2013). The project addressed leakage of polluted effluent from a municipal landfill into an informal settlement of roughly 10,000 people living atop the landfill. The settlement and improper containment of municipal waste was a risk to public and environmental health, and housing in the settlement was improperly constructed and subject to toxic flooding and landslides during heavy rain. The collaboration was initiated by the City of Medellín who sought assistance from UPC in designing a stakeholder engagement process to co-create a solution to the problem, following a top-down process that was ultimately unsuccessful. As part of the current state analysis, the problem was collaboratively framed and analyzed, as well as community needs were identified. This was done in collaboration with the university, city, and members of the community. Researchers identified the best available technological solution, reducing the health risks and building community gardens and constructed wetlands to treat contaminated runoff on site. The solution, implemented as part of the project, was informed by community priorities, but drew heavily from environmental remediation experiences in Barcelona where a former landfill was sealed and converted to a public garden. This was a research project focused on the implementation of best available technology solutions. Outputs included new infrastructure, as gardens and wetlands were constructed atop the sealed landfill, new livelihood opportunities, and a social network was created as a community co-op was formed to operate and maintain the constructed wetlands and cultivate and sell flowers grown from the gardens.

Stellenbosch University: research focus and planning focus

University researchers are working with the municipality of Stellenbosch on addressing unsustainable urban sprawl and lack of access to transportation, goods and services in Stellenbosch. The project *Re-imagining and Co-Designing the Future of Stellenbosch—Towards a Transit-Oriented*

Development Approach began in 2010, is still in progress, and was initiated and funded by the municipality (Davies and Swilling 2015). The municipality reached out to university researchers to co-develop new planning guidelines for Stellenbosch to build a more compact, sustainable and inclusive city, while helping to address the legacy effects of apartheid. The project is ongoing with Stellenbosch municipality as project lead and STB as key collaborator. Strategic working groups were formed as part of the current state analysis and strategic planning efforts. They were tasked with developing a new spatial development plan for the city informed by visions of a sustainable Stellenbosch. Working groups continue to meet weekly to develop the transportation oriented development (TOD) approach and address a backlog of transportation and infrastructure issues before moving ahead with new plans. This is a research project focused on developing a TOD plan for Stellenbosch. Current outputs include a new spatial development framework and scenarios of TOD for Stellenbosch. Outcomes include a strong, collaborative working relationship established between the city and the university.

The University of Tokyo: teaching focus and planning focus

In 2013, the UT conducted a graduate course on food security in areas prone to disasters such as earthquakes, tsunamis, and typhoons, including a case study on Bang Krachao, Thailand (Yarime et al. 2012). Students analyzed the current state of food security prior and after the natural disasters in Bang Krachao through the literature review and in class lectures. Students then traveled to Bang Krachao for a week-long experiential study tour. Here, students consulted with members of the local community to learn more about the specific food security issues they face. Students, coached by faculty members, finally developed a strategy for enhancing food security in Bang Krachao. This was an educational project that aimed to develop plans for food security. Outputs included design models for urban gardens, among other outputs from student projects. Outcomes included improved student awareness of local problem contexts.

Arizona State University: teaching focus and implementation focus

The educational project *Revitalizing Public Spaces for the Public Good in Phoenix* addressed the challenge that public spaces catering to the needs of the community are extremely sparse in the Gateway district of Phoenix, Arizona. The project, which ran from 2013 to 2014, was a collaboration between students and faculty from different

programs at ASU and various external partners, including Crockett Elementary School, Balsz School District, Maricopa County Department of Public Health, and City of Phoenix' Neighborhood Services Department (Wiek et al. 2016; Wiek and Kay 2015). The primary goal of the project was to educate students in urban sustainability transitions, while fostering social cohesion through positive real-world changes in public spaces in Phoenix. The project was part of the collaborative international educational program "The Global Classroom" by ASU and Leuphana University which had an array of educational objectives and activities (Wiek et al. 2013). The project targeted a specific site in Phoenix for transition experiments, namely Crockett Elementary School in the Gateway district. The first experiment yielded a plan for a community vision mural, which was then created in a public painting event at a wall visible to the community. The second experiment yielded a design of a school orchard and shade trees, which were

planted afterwards. The third experiment resulted in a draft joint use agreement between the school and a consortium of governmental and non-profit organizations, which turns the school's playground, fields, and gymnasium into public space after normal closing hours. Follow-up evaluations are planned to make insights from these urban transition experiments accessible to a broader audience (cf. Forrest and Wiek 2014).

International collaboration on sustainability solutions

We distinguish four ways in which international networks can be utilized to advance research and teaching on sustainability solutions, respectively (Tables 2, 3). In this section, we demonstrate how projects within NEPS can be expanded or leveraged through existing and hypothetical

Table 2 Types of research collaborations on sustainability solutions in international networks (with increasing intensity of collaboration from left to right)

Research collaboration	Type 1 Solution adoption	Type 2 Solution consultation	Type 3 Joint research on different problems	Type 4 Joint research on similar problems
What is being addressed?	Problem	Problem	Different problems	Similar problems
At how many sites?	One	One	Two or more	Two or more
What is being generated?	Solution	Solution	Similar solutions	Similar solutions
How do the partners interact?	Virtual	In person	Virtual	In person
How do partners collaborate?	Consultative	Consultative	Collaborative	Collaborative
What is being exchanged?	Solution option	Expertise	Solution options	Solution options
NEPS examples	Garden: Barcelona → UPC	Governance: UNAM ← MAU	Land use: Tokyo ↔ UNAM	Local economy: LUL ↔ ASU

Table 3 Types of teaching collaborations on sustainability solutions in international networks (with increasing intensity of collaboration from left to right)

Teaching collaboration	Type 1 Adopted course	Type 2 Course visiting faculty	Type 3 Joint Course Traveling Faculty	Type 4 Joint course traveling students
What is being taught?	Sustainability competencies	Sustainability competencies	Sustainability competencies	Sustainability competencies
At how many partner universities?	One	One	Two or more	Two or more
Who teaches?	Home faculty	Home faculty and visiting faculty	Traveling faculty	Home faculty and traveling faculty
How do partner faculty interact with students?	Virtual	In person	In person (short period) and virtual	Virtual and in person
How do students across partner universities interact?	None	None	Virtual	Virtual and in person
NEPS examples	TOD: STB → UPC	Evaluation: MAU → ASU	Local food: LUL ↔ Lund	Disasters: UT ↔ UNAM

partnerships within the network. These partnerships form the basis of two typologies: Typology of International Research Collaborations and Typology of International Teaching Collaborations. The types within each typology are derived inductively from analysis of the cases and deductively from the literature on [international] university partnerships. While we support the place-based nature of transformational sustainability research, we recognize its limits in creating generalizable and even transferable knowledge, and offer here ways to extend existing sustainability research and teaching at individual universities to accelerate progress toward sustainability around the world within these limitations.

For both the research and teaching typologies, the four types are characterized along their key features, including objectives, content, the number of sites involved, and the form of the collaboration, and are illustrated by extending the eight project profiles of NEPS partners summarized in Table 1. Here, “site” indicates *where* a particular university is working, i.e., *where* particular issues are being addressed. The site can be a neighborhood, a city, a regional network, a sector, and so forth. The types are ordered with respect to the intensity of collaboration among partner universities, with type 1 tending toward the lowest and type 4 tending toward the highest intensity of collaboration.

International research collaborations

Type 1: solution adoption

International networks can help facilitate the transfer of a sustainability solution from one partner university to another. In this case, there is *a solution* that is being adopted by a partner university and applied to *one particular site*. This is an *adoption of research insights and outputs*, rather than an exchange of personnel and their expertise. This type of collaboration was exemplified in UPC’s project in Medellín. UPC used the experience of Barcelona, where a landfill adjacent to the Olympic area was transformed to a public botanical garden, as the inspiration for the transformation of the Medellín landfill to a community garden (Restrepo 2011). The solution was adopted in Medellín—to transform the Moravia landfill into a garden—and adapted to the particular problem and solution context by creating a community garden (rather than botanical garden) that produced flowers for sale by community members. By adopting an existing solution, time and money are saved for allocation in the critical implementation phase. Similar solution adoptions could be facilitated across NEPS partner universities. For example, the UT’s graduate course could investigate how landfills and other contaminated sites in Tokyo and elsewhere could

be remediated with gardens to improve food security. By utilizing a network to *share similar solutions and research outputs across cases*, universities can avoid reinventing the wheel in their search for sustainability solutions, conserve resources for testing, implementing and evaluating solutions in specific local contexts, as well as avoid unintended side effects and failures.

Type 2: solution consultation

International networks can also be utilized for partnerships between two or more universities to develop solutions together for one partner (e.g., Preece et al. 2000). This is a consultative partnership in which one or more partners translate place-based knowledge on a particular solution into generalizable knowledge that can then be specified and adopted by another partner. For example, Maastricht University has experience with experimental governance that could inform planning and implementation of solutions at Universidad Autónoma de México (UNAM) in Mexico City. Within the Megadapt project, researchers are engaging with local actors, including government officials, to establish a shared understanding of sustainability problems within the local water system. Utilizing an international network for *solution consultation*, UNAM could consult with Maastricht University researchers to develop the next phases of research. If a solution to Mexico City’s water challenges requires new forms of water governance, they could capitalize on Maastricht’s expertise in experimental forms of governance that are intended to yield sustainable outcomes. By utilizing networks for consultation on solution options, universities can capitalize on existing research and expertise from partner universities and reduce unnecessary redundancies to hasten the development and implementation of contextually appropriate sustainability solutions.

Type 3: joint research on different problems

International networks can also help facilitate joint research on different problems while still developing solution options together. This entails a clear *bi-directional exchange between two or more universities*, in which *research outputs and solutions* as well as *researchers’ expertise* are shared to facilitate mutual learning, e.g., in the form of an international learning network (Talwar et al. 2011). For example, the UT is researching opportunities for sustainable food access in Bang Krachao, while UNAM is researching problems within the water system in Mexico City. Obviously, these are different problem manifestations. Yet, if viewed as part of larger sustainability syndromes, e.g., Rural Exodus Syndrome, or Overexploitation Syndrome (Lüdeke et al. 2004), there are similarities across

contexts that can inform similar solutions. For both problem contexts, historical changes to land use laid the foundation for the current problems, namely, establishing a clear urban–rural divide in Bangkok, and building canals and draining a large lake to accommodate population growth in Mexico City. Both cities are in disaster prone areas and alterations in land use have made current populations vulnerable to these disasters in ways that historical populations were not. In planning and implementing sustainability solutions to these problems, UT and UNAM could establish a joint research project on how historical models of land use can be adapted and modernized to reduce vulnerabilities and help modern cities live with disasters instead of against them. In this way, international networks are instruments of collaboration and mutual learning in which researchers dealing with different problems in different places find commonalities and shared solution options.

Type 4: joint research on similar problems

International networks can finally help facilitate joint research on similar sustainability problems. Partners can *share knowledge and personnel across sites* by establishing joint research projects, e.g., with co-PIs at partner institutions and shared funding sources. For example, Lüneburg, Germany and Phoenix, Arizona—cities of different sizes and histories—both engage in unsustainable consumption patterns and struggle with what will sustain their economies in the twenty-first century. One proposed solution to globalization and economic insecurity is a focus on developing sustainable local economies. Leuphana University with the Buy Local Network has experience developing a local living economy in Lüneburg and Phoenix is home to one of the largest Buy Local Initiatives in the US, Local First Arizona. Leuphana and ASU researchers could partner to jointly conduct research on currently dominating business models as well as on sustainable local economies in Lüneburg and Phoenix. This type of collaboration can help to accelerate learning from and with partner universities addressing similar problems and striving for similar solutions, while still taking into account local contexts.

International teaching collaborations

Type 1: adopted course

International networks can be utilized to build student competence and capitalize on partner experience to minimize redundancy and limit faculty burnout (e.g., from time-consuming and complex teaching obligations) by sharing *courses* between network partners. In this type of

teaching collaboration, a course is developed at one university; material is then adopted and adapted by partner faculty to fit the program needs and problem contexts of their universities. This could be an online, classroom-based, or blended (hybrid) course. For example, STB has developed a course linked to the project *Re-imagining and Co-Designing the Future of Stellenbosch: Towards a TOD Approach* project. Course material and pedagogical approaches have been developed to facilitate student learning in transdisciplinary projects with local government actors. For example, UPC could adopt this course content, if they were interested in designing a course and involving students in the *Environmental Restoration Plan of the Morro de Moravia, in Medellin, Colombia* project. By adopting courses from partners within an international network, a project can reduce the financial and time costs associated with developing a new course, while allowing more students access to established high-quality courses.

Type 2: course with visiting faculty

International networks can be used to share faculty. Faculty can visit partner universities to give a course that may not otherwise be available. For example, Maastricht University has experience with evaluation through their *URBAN Experiments with Living Labs & City Labs (URB@Exp)* project. Normative competence in sustainability requires that students are able to apply evaluation methods in sustainability projects. In this type of teaching collaboration, a competent faculty member from Maastricht University could develop or adapt a course related to evaluating sustainability and visit ASU to teach all or part of such course. In a follow up to the *Revitalizing Public Spaces for Public Good* project at ASU, the faculty member from Maastricht University could offer a course on program evaluation to ASU students that would enable them to take a closer look at the impacts of the project. By utilizing international networks to share faculty and their courses, partners can offer their students broader and cost-efficient exposure to sustainability topics and opportunities for competence development.

Type 3: joint course with traveling faculty

Courses can also be taught across multiple partner universities within an international network and faculty can travel between universities to allow for in-person co-teaching of such courses. In this type, students engage with one another virtually and with faculty virtually and in person. While joint courses can exist without traveling faculty (purely online), the exchange of faculty allows for greater utilization of network resources. Blended (hybrid) learning environments can better help students apply their

acquired knowledge and skill as well as build a sense of community—which are particularly critical for international sustainability education (Rovai and Jordan 2004; Ayala 2009). For example, Lund University links concepts of local living economies with a sustainable supply chain in the *Knowledge to Action for Sustainable Development* course. The professor at Lund University could design a distributed seminar across NEPS partner universities on establishing sustainable supply chains, which could be applied locally by partner students. To facilitate student learning, the faculty member could travel between partner universities giving in-person lectures and working with students to tailor the course to the respective local context. Such a course could be taught, for instance, between Lund and Leuphana (LUL). LUL has experience with the Buy Local Initiative and students who engage with sustainable local economies at LUL could benefit from the *Knowledge to Action for Sustainable Development* course's global perspective. This type of teaching collaboration allows students from different universities to engage with one another through a shared course, develop cross-cultural competence, learn from the perspectives of their peers, and benefit from closer collaboration with faculty from partner universities.

Type 4: joint course with traveling students

In the most intense type of teaching collaboration, international networks can bring students and faculty together at multiple universities through joint courses. This can be done in several ways. For example, the UT teaching studio on food security and urban fringe landscapes could be extended to UNAM to develop a joint course on sustainability in disaster prone areas. By utilizing international networks to bring students together to work on place-based sustainability issues, students learn how sustainability problems manifest locally by experiencing the local context and from their peers who live in the study area. They also confront the limits to transferability of solutions that may work well in their region, but not elsewhere (at least not without modifications). Students from the host university gain the perspective of their international peers on local problems and potential solutions while learning more about their own community through presenting and reflecting on familiar issues, often taken for granted. Expanding on a single joint course, universities can establish joint programs where students work in teams across two or more universities on place-based issues in local communities. In the case of ASU and LUL, a multi-semester joint course has been established between the two universities to educate students in sustainability problem-solving and build intercultural competence (Wiek et al. 2013; Leuphana University of Lüneburg 2014).

Undergraduate students spend three semesters taking courses taught in-person and online by instructors from ASU and LUL and working in teams across the universities. The students work on place-based sustainability problems and solutions in Phoenix and Lüneburg. During the program, Leuphana students and faculty travel once to ASU and vice versa. Students build interpersonal and intercultural competence by conducting research in international teams, managing communications and data across nine time zones, with different web interfaces, and with differences in language and culture. While this structure is labor intensive for students and faculty, it is a compelling model for education that builds capacity for global sustainability leadership. By utilizing international networks to establish joint courses with traveling faculty and students, all who participate are given the opportunity to conduct place-based sustainability research and develop a deeper appreciation of the contextual differences in sustainability problems and solutions across countries and cultures.

Discussion and conclusions

Under the paradigm of transformational sustainability science universities are engaging in a number of innovative research and education endeavors to plan and evaluate solutions to sustainability challenges. These solutions are place-based, but their impact can be extended through international networks. How a project can be extended depends on the research or teaching process and the outputs and outcomes. For example, research projects on solution implementation lend themselves well to an exchange of the solution itself or the co-production of a solution (International Research Collaborations types 1 and 2). In this regard, the typology is intended to guide the extension of existing projects or the creation of new projects with international components. However, this is not an exhaustive typology of international collaborations in research and education. Rather, this work adds a practical typology that could guide the development or extension of international collaborations in transformational sustainability science to the growing literature on university partnerships (Corcoran and Wals 2004; Wiek et al. 2013; Trencher et al. 2014a; Trencher and Bai 2016).

International networks can provide many opportunities for universities to learn together and learn from each other. The urgency of sustainability problems demands that sustainability science utilizes such networks to their full capacity to develop specific and generalizable insights on sustainability solutions and disseminate methods, results, and best practices for research and teaching. This requires a collaborative mindset among participating universities,

faculty, and students—driven by the need to address urgent sustainability challenges and in spite of potentially conflicting obligations of funding, publications, tenure, teaching, and course requirements. This article focuses on research and teaching collaborations at the level of projects and courses. While this article differentiates between activities that are primarily research focused and primarily teaching focused, this line is often blurred. This is reflected in the typology indicating that insights from primarily research projects can be extended to teaching projects and vice versa. The described courses and projects are intended to build *collective* capacity of sustainability problem-solving. There are, however, other types of *individualized* collaborations that build *individual* capacity and might be well facilitated by international networks, such as individual student exchanges, visiting students and faculty, or cross-appointments of faculty. There are also more extensive forms of collaboration, such as establishing joint degree programs and joint institutes. ASU and Leuphana, for example, are building on the Global Classroom model by establishing a double degree Master's program in Sustainability Science beginning in Fall 2015 (Leuphana University of Lüneburg 2015).

We conclude this article with a few initial reflections on what is necessary and/or desirable to make these collaborations happen or, in other words, to move from individual projects to collaborative projects through international networks. Instead of narrowly focusing on any one of the above-described types, we offer more general suggestions on how to shape such an international network to build research and teaching collaborations that accelerate learning.

An easy start seems to be creating an online platform where interested students can engage with one another across partner universities. This pays tribute to the fact that by far not all international collaborations need to be initiated by faculty. Often students are inspired and enthusiastic about international collaboration and have the time and energy to engage with other students across partner universities. With moderate faculty encouragement and administrative assistance online platforms can enable students to co-shape joint courses and projects. And students' interest can become a major source for initializing or keeping the momentum for establishing international collaboration.

International collaborative efforts of the types described above would be well served by appointing select faculty as *international ambassadors* at each partner university to explore and foster potential collaborations between partner universities within a network. Rather than expensive and at times unproductive plenary meetings with all members of a network, a university can send a single ambassador to multiple partner universities to hold targeted meetings to set up collaborations.

At a later stage of institutional development, the network might be able to designate an *international coordinator* responsible for supporting collaborative arrangements across partner universities. Such a coordinator would foster organizational learning across the network and maintain a network 'memory'—providing information, facilitate collaborative arrangements, do trouble shooting, if necessary, and evaluate success and failure of collaborative efforts. Considering the inter- and transdisciplinary nature of almost all empirical sustainability projects, such a coordinator might benefit from specific training on how to facilitate collaboration at several interfaces (e.g., between disciplines or between scientists and stakeholders) (Brundiers et al. 2013).

A further step in the institutional development would be the establishing of joint research institutes across partner universities. This level of institutionalizing partnerships across universities around the world, while tedious in its administrative establishment, can yield many positive results and enable a culture of international collaboration that goes far beyond isolated institutional successes. Not only allowing, but fostering and celebrating international collaboration on this level promises great acceleration in making progress on sustainability issues worldwide. As an example, LUL and ASU are just about to create such a joint sustainability institute, as the nucleus for furthering the institutionalization of NEPS.

Each type of collaboration will have a unique set of associated institutional challenges. For solution adoption and course adoption, there may need to be copyright issues sorted out. For joint courses, there can be differences in time zones, semester schedules, and degree requirements. These and other issues must not hamper international collaboration, but do require time, personnel and financial resources to address. However, international collaboration of the kind described here can save universities time and money in other areas, e.g., through sharing of faculty time spent on course development across universities, and possibly be leveraged for additional opportunities and in-kind funding at each university, e.g., through increased enrolment driven by the greater market appeal of international courses and programs. It is clear, however, that for all types of international collaboration, some kind of funding is needed, particularly to establish and maintain collaborations. The range of organizations willing to fund such activities is increasingly broadening, now ranging from federal agencies, regional agencies, international organizations, corporations, and private foundations. It requires persistence in developing these essential institutional relationships, and the proposed typologies can help applicants to more systematically explore and position the type of international collaboration they intend to propose. The typologies might also be used as aids by funding

organizations to structure their programs, which, in return, would allow applicants from international networks to state their case more easily and successfully. The traditional university structure often hinders international collaborations, perpetuating many of the challenges outlined above. Creating formalized agreements to exchange knowledge and personnel can help overcome some of those barriers, but transformation within universities is necessary to realize the full potential of international partnerships.

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