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Exploring Julie Thompson Klein's Framework for Analysis of Boundary Work

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Abstract: Julie Thompson Klein's contributions to interdisciplinary and transdisciplinary research have enriched the way collaboration is discussed and handled by introducing concepts of boundary work and boundary crossing from the field of Science and Technology Studies. In recent years, she has been integrating those concepts into crossdisciplinarity, an effort culminating in the development of a framework for a forthcoming book (*Beyond Interdisciplinarity: Boundary Work, Collaboration, and Communication in the 21st Century*). With her permission, we have used an earlier version of her framework to analyze boundary work and boundary crossing in transdisciplinary sustainable water management projects in Australia and Switzerland. The aim of using the framework has been twofold: to explore and assess the

heuristic value of the framework, i.e. how it improves our conceptualization of boundary work in the two projects, and to examine the framework itself, i.e. whether some of the seven concepts involved are hard to work with or should be further developed.

Keywords: boundary crossing, boundary work, facilitating expertise, facilitating leadership, interdisciplinarity, Julie Thompson Klein, transdisciplinarity

1. Introduction

In her book *Crossing Boundaries. Knowledge, Disciplinarities, and Interdisciplinarities* (Klein, 1996), Julie Thompson Klein brought together concepts and theories from the field of interdisciplinarity and transdisciplinarity with concepts and theories of boundary work and boundary crossing from the field of Science and Technology Studies. Bridging these fields allowed new concepts to emerge for understanding and facilitating interdisciplinary and later also transdisciplinary collaborations. These new concepts enabled richer conceptualization of how boundaries between disciplines or between academia and society are constructed and maintained and of how boundary objects or interlanguages can help to bridge different subcultures and improve the way their members communicate. Since then, Klein has further elaborated the concepts of boundary work and boundary crossing, an effort culminating in the development of an analytical framework for a forthcoming book, *Beyond Interdisciplinarity: Boundary Work, Collaboration, and Communication in the 21st Century*. Klein developed an earlier version of the framework for analyzing boundary work for a joint paper with the lead author. That paper stayed a draft. However, in the following, with not only her permission but also her strong encouragement, we will present, report on the use of, and review this framework. In section two of this article, we introduce the framework, drawing mostly from the words of Klein taken from the draft paper. In section three we discuss our use of the conceptual framework to analyze two of our own projects. Both are from the field of sustainable water management, one from Australia and the other from Switzerland. The aim of using the framework is twofold: to explore and assess the heuristic value of the framework, that is, how it improves our conceptualization of boundary work in the two projects, and to examine the framework itself, i.e. whether some of the seven concepts involved in the framework are hard to work with or should be further developed. We address both those matters in section four.

2. Klein's Conceptual Framework for Analysis of Boundary Work

In the following we present Klein's conceptual framework for analysis of boundary work: a set of seven concepts expressed as questions in an analyti-

cal frame to explore boundary work of interdisciplinary and transdisciplinary teams. We introduce and explicate each concept, then reframe each concept as a question to guide reflection and analysis (see Table 1).

Concept 1: Boundary Work

Boundary work is the most generic concept in the framework. According to Klein, it is a composite label for the claims, activities, and structures by which boundaries are created, maintained, crossed, and reformulated between knowledge units. Knowledge units are built, for instance, by the members of a discipline (Fleck, 1986) or of a community of practice (Wenger, McDermott, & Snyder, 2002) that reaches beyond academia. Initial studies of boundary work focused on science and disciplinarity, though subsequently the concept was extended to studies of interdisciplinarity (Fisher, 1993, pp. 13-17; Gieryn, 1983; Klein, 1996, pp. 57-84). The concept adequately represents the complexity and multidimensionality of boundary crossing that occurs in many areas dubbed "interdisciplinary." Research and education on problems of Health and Wellness, for example, cross boundaries of expertise in academic disciplines as well as professions of medicine, social work, education, law, and other occupational groups. Hence, in this case the concept involves both interdisciplinarity and interprofessionalism (D'Amour & Oandasan, 2005). Interdisciplinary research also crosses boundaries of social sectors beyond the academy, leading Rustom Roy (2000) to propose the term "interactive research" to refer to alliances with governments and industry. Sustainability is another powerful example of an area involving much boundary crossing (Hirsch Hadorn, Bradley, Pohl, Rist, & Wiesmann, 2006; Jahn, Bergmann, & Keil, 2012). In both instances – Health and Wellness and Sustainability – different connotations of the terms "interdisciplinary" and "transdisciplinarity" appear, leading to several classifications of research and education being labeled with the terms (Huutoniemi, Klein, Bruun, & Hukkinen, 2010; Klein, 2010; Pohl & Hirsch Hadorn, 2007, pp. 69-95). For instance, "transdisciplinarity" might include trans-sector problem-oriented research that involves both academics and stakeholders in society (Hirsch Hadorn et al., 2008) and Patricia Rosenfield's (1992) notion of "transcendent interdisciplinary research" that creates new methodological and theoretical frameworks.

The first question to consider in analyzing any particular case study, then, is the following: What forms of boundary work are evident, factoring in the range of interdisciplinary, interprofessional, interactive, and transdisciplinary approaches?

Concept 2: Subcultures

A second concept involves academic tribes and cultures (Becher, 1989). Researchers collaborating in an interdisciplinary or transdisciplinary project can be seen as belonging to different academic tribes and cultures (i.e. disciplines or sub-disciplines), each of which inhabits, develops, and defends a particular territory of knowledge. Accordingly, in interdisciplinary and transdisciplinary collaborations members of different subcultures meet, exchange, and might argue about who has the final say on a particular topic. Depending on the project, further subcultures involved might represent the private sector, the public sector, or civil society.

The second question in our framework follows: What are the different subcultures, their differences, and their basis for exchanges?

Concept 3: Expertise

Gorman and colleagues (2002; 2010) speak of trading zones as a "space for exchange" where representatives of heterogenous disciplines are capable of producing a new homogeneous culture of "interactional expertise." Sociologists of science Collins and Evans (2002, p. 254) further distinguish between "interactional expertise" and "contributory expertise." "Interactional expertise" ("enough expertise to interact interestingly with participants and carry out a sociological analysis") refers to members of different subcultures who understand enough of the languages and norms of the other subcultures involved in a zone to have an interesting and stimulating exchange or to trade expertise. "Contributory expertise" ("enough expertise to contribute to the science of the field being analyzed") involves individuals who have learned enough about other disciplines to make original contributions. For Gorman (2002; 2010) the two kinds of expertise differ in intensity of collaboration: Interactional expertise is an exchange – or trading of expertise – on a more or less well defined boundary object (see below) not requiring a shared language or shared understanding. Contributory expertise, by contrast, would require an in-depth knowledge of the language and norms of other subcultures and of how representatives of each perceive the joint subject of research.

The third question arises from this deepening of the concept of boundary work and asks: What forms of expertise exist in the team? How do they change in the process of participants' work with others?

Concept 4: Boundary Objects

The next concept in the framework – boundary objects – plays a productive

role in mediating differences within trading zones without requiring a shared representation of the subject of research. Following Star and Griesmer's definition (1989), boundary objects are robust enough to maintain unity across practices but plastic enough to be delimited, manipulated, and bounded in individual practices and at local sites around a common interest but still retain separate interpretations. Particular technologies – for example, creation of the Mars Rover and development of Berkeley's Museum of Vertebrate Zoology – have been focal points for collective work among individuals from different subcultures. Exchange was possible because the objects were plastic enough to be adapted to local needs and constraints but still robust enough to maintain common identity. Other examples of boundary objects would be data (numbers) and data sources (rabbits) shared between labs and sometimes brought together for comparative analysis. Or molecules built by one research group and analyzed by another group, with both sides bringing insights to the final results. Or, for faculty from different disciplines in an interdisciplinary studies program, the boundary object could be the curriculum and the degree(s) to collectively work and agree upon. And, in the context of a large transdisciplinary research project on urban transportation in Germany, the concept of mobility operated as a boundary object that framed the process of identifying the main research question (Bergmann & Jahn, 2008).

The fourth question in the framework follows in turn: What technologies, products, concepts, or ideas function as boundary objects, enabling members of a team to trade expertise on a common point of reference?

Concept 5: Interlanguages

The concept of trading zones was borrowed from anthropology (Galison, 1997) but companion concepts of pidgin and creole are familiar in linguistics. The metaphor of bilingualism is a popular characterization of interdisciplinary work. However, it is not an accurate description of what happens in most projects. Interdisciplinary discussions, Gerhard Frey (1973) found, typically occur on a level similar to that of a popular scholarly presentation. They become more precise in phrasing as individuals acquire knowledge of other disciplines, combining everyday and specialist language. Disagreements in teamwork often boil down to disputes over language: people using the same words with different intended meanings. Interdisciplinary language typically evolves through development of an interlanguage. In accordance with the metaphor of trading zones, a pidgin language is an interim tongue devised to facilitate dialogue among subcultures. A creole is a new first language among members of a new social and cognitive community (Klein, 1996, p. 220).

Broadly speaking, the quality of outcomes in interdisciplinary projects, as Wilhelm Vosskamp (1994) observes, cannot be separated from the develop-

ment and richness of a shared language culture. Schmithals and Berkenhagen's notion of a "cooperation and communication culture" highlights the importance of paying attention to interfaces: to the points where the work of one participant is necessary for the work of another, and to the points where participants must coordinate effectively with one another (Schmithals & Berkenhagen, 2004). Shared language, Bruce Thiessen further urges, requires adaptive behavior to achieve common ground for establishing shared language and goal-directedness at both the group level and in individual capacity for collaboration (Thiessen, 1998, pp. 49-50).

The fifth question of the framework, then, highlights the role of language: What kinds of interlanguage have developed over the course of a project, and did they evolve from a pidgin to a creole, and did a shared language culture emerge?

Concepts 6 and 7: Collaborative Learning and Leadership

As Burtis and Turman observe in their book on the subject, all group communication engages in "boundary spanning" – that is, knowledge exchange between subcultures (Bednarek et al., 2018) – necessitating "boundary negotiations" in both internal and external communications (Burtis & Turman, 2006, pp. 53-54). Spanning and negotiation take on greater weight in interdisciplinary collaboration because worldviews must be bridged. There is no single unified model for interdisciplinary research (IDR) and transdisciplinary research (TDR) collaboration, but every project or program requires the creation of a platform of communication, creating a space and a network for developing shared goals, concrete ideas and measures, and assessment (Hindenlang, Heeb, & Roux, 2008, p. 243). On-going communication and interaction foster mutual learning among individuals as well as a sense of interdependence. The last key concept in the framework – single versus double loop learning – accentuates the difference between learning that issues in minimal change (single loop learning) versus learning that issues in fundamental change in the underlying assumptions of an organizational system (double loop learning). Double loop learning calls into question operant mental models, mindsets, and frames of reference. Goals and values are open to change, bringing the possibility of creative, innovative, emergent outcomes (Argyris, 1976).

The penultimate question underscores the importance of learning: What activities have fostered collaborative learning and new hybrid expertise among the individuals and the entire team?

The final question follows the previous one by asking how and by whom the process of collaborative learning is organized: What leadership and management strategies have enhanced the prospect for communication and collaboration?

Table 1
Framework to analyze boundary work in interdisciplinary teams

	Concept	**Specific questions**
1	Boundary Work	What forms of boundary work are evident, factoring in the range of interdisciplinary, interprofessional, interactive, and transdisciplinary approaches?
2	Subcultures	What are the different subcultures, their differences, and their basis for exchanges?
3	Expertise	What forms of expertise exist in the team? How do they change in the process of participants' work with others?
4	Boundary Objects	What technologies, products, concepts, or ideas function as boundary objects, enabling members to work together on a common point of reference?
5	Interlanguages	What kinds of interlanguage have developed over the course of a project, and did they evolve from a pidgin to a creole, and did a shared language culture emerge?
6	Collaborative Learning	What activities have fostered collaborative learning and new hybrid expertise among the individuals and the entire team?
7	Leadership	What leadership and management strategies have enhanced the prospect for communication and collaboration?

3. Analyzing Boundary Work in Two Sustainable Water Management Projects

Below we use Klein's conceptual framework (Table 1) to analyze two sustainable water management projects, one from Australia and one from Switzerland. We focus on sustainable water management because it is the field of expertise for three of the authors. For each analysis, we first briefly describe the project and then apply selected concepts of the framework, specifically those deemed most relevant for the project.

3a. The Australian Case

The Australian case study analyzed for this article involved installing a novel system of sanitation – Urine Diversion (UD) – in a multi-story build-

UD systems aim to separate and collect urine from the wastewater stream for processing as an alternative fertilizer in agricultural production (Fam, Mitchell, Abeysuriya, & Meek, 2013). UD systems are a relatively novel technology within Australia with only four trial installations across Australia at the time of this project. Installing UD systems on the university campus at UTS required bridging multiple dimensions of UD to learn about the technological, social, and regulatory factors influencing the successful installation and management of UD systems. There was a lack of knowledge and expertise in installing, operating, and regulating UD systems by water utilities, councils, and regulators, making social learning and boundary work a critical and necessary process in the project (Fam, 2017). The overarching research frame of TDR was therefore informed by action research methodology (Dick, 2001).

Concept/Subcultures: What are the different subcultures, their differences, and their basis for exchanges?

The UD trial at UTS engaged a range of researchers, staff, and students (undergraduate and postgraduate) along with key industry and government stakeholders. This Community of Practice (CoP) (Wenger, 2004) provided cross-disciplinary expertise, drawing together 15 collaborators across six disciplinary faculties, five industry sectors, and three government departments (see Table 2 for further details).

Table 2
Collaborators involved in the UTS trial across academia, industry, and government (Fam, 2017)

Academia from three Universities	Industry	Government
• Law • Agriculture • Design • Engineering • Sustainability Science • Systems Thinking	• Toilet Manufacturer • Horticulture Nursery and Garden Industry Association • Water Utility • Design and Construction • Building Facilities Management	• Local Council • Plumbing Industry Regulator • Department of Health

In terms of subcultures and their basis for exchanges, the academy can be contrasted with industry: In those two spheres there were distinct subcultures with differing agendas and interests in this project. For example, many of the disciplinary academics invited into the project brought with them a primary focus on disciplinary-oriented inquiry, which created barriers to active cross-disciplinary participation. Their lack of experience in inter- and transdisciplinary forms of research meant that their strong preference was to remain within their silos, conducting a solely legal or design or engineering inquiry. Embedded institutional structures and resource allocation also limited the collaboration among disciplinary departments and between universities, factors clearly noted by other scholars researching trans-, inter- and multidisciplinary collaboration (Stokols, 2006). In this case, as so often, academics were driven by the "politics of research" (Altman, 1995) and the need to publish research and fulfill expectations of their academic institutions. In the UTS case, the perceived incentives for academic collaboration (in lieu of financial payment) were intellectual outputs such as the development of conceptual frameworks, methodologies, empirical studies, and peer-reviewed publications satisfying institutional requirements to generate research outcomes (Fam, 2017). Some academics were disinclined to participate in this TDR project due to lack of institutional support. Overcoming this disincentive required renegotiating incentives for academics involved to meet institutional requirements. For example, we reviewed and revised the budget so that academics could be offered small financial incentives to support them in developing expected research outputs. Academics who were leading areas of research did so to meet individual goals as well as expectations of their associated institutions and were more likely to participate and lead research when there were opportunities to incorporate elements of the project's research into their teaching (e.g. student projects) and/or to publish research outcomes.

For those beyond the academy, the extent of partnering and engaging in the project varied significantly due to the diversity of industry and government members involved (see Table 2): Perceptions of benefits and the potential for direct gains differed greatly amongst these members. For example, the toilet manufacturer conducted tests of international products against Australian Standards, which provided an opportunity to examine other designs carefully. The design and construction company learned about what pitfalls to avoid in building successful urine diversion pipework in multistory buildings. The plumbing regulator recognized the need for change in the sector, so their contribution, or the form of their exchange, was to shepherd our project through strict regulatory approval processes, thereby

creating a path for potential innovation at scale, following our pilot project.

Concept/Expertise: What forms of expertise exist in the team? How do they change in the process of participants' work with others?

At the time of this project, the Project Director had approximately a decade of experience in leading TDR, firstly through pursuing projects with and for industry that sought to employ the scholarship of integration (Boyer, 1997), i.e. beyond "application," and secondly through creating enabling environments for TDR, especially through her leadership of a transdisciplinary doctoral research program that adopted elements of CoP in its orientation (Riedy, Fam, Ross, & Mitchell, 2018). Deep engagement over time with questions of what constitutes quality in TDR meant that the Project Director had developed a broad, pluralist stance in epistemological terms, and had by then much experience in helping disparate groups negotiate the epistemological chasms between disciplines. This expertise is neither interactional nor contributory in the sense Collins and Evans use the terms (2002, p. 254). It is not expertise in the content of a dialogue, but in making a dialogue happen, and we call it "facilitating expertise."

Facilitating expertise was important not only for the design of the project, but also for the implementation of the project. For example, industry partners in the project were familiar with research projects designed to follow a linear process, passing milestones and delivering a set of pre-determined outcomes. In this project, we aimed to take an emergent approach, leaving open the potential to change key elements and directions of the project as our exploration continued, integrating learning into the facilitation of the research. This approach to delivering the project was novel and initially confusing to our industry partners. However, our facilitating expertise meant we were able to carefully negotiate the process of the project in a way that enabled our industry partners to come to view emergence as a legitimate part of the research process. As one team member from industry recalled, "I think at the beginning I was very unclear of the scope of the project and then I realised the reason I'm unclear about the scope is because it is actually changing." Given that the drivers for innovation are much weaker in the water industry than elsewhere (Dolata, 2009; Mitchell, Abeysuriya, Willetts, & Fam, 2010), this acceptance of the new by industry partners was a significant result.

Concept/Boundary Objects: What technologies, products, concepts, or ideas function as boundary objects, enabling members to work together on a common point of reference?

The two main boundary objects were the evolving schematic of the conceptual approach (Figures 1 and 2) developed in the proposal stage and a systems diagram developed during the project (Figure 3). Together, TDR and action research provided a flexible and learning-focused approach to the project. In the project design, we sought to distinguish multiple distinct (but not disciplinary) strands of potential inquiry as well as to make explicit the need from a systems perspective to pay attention to integrating these separate strands. Each strand (Technology, Visual Communication, Stakeholder Engagement, Regulations/Institution, and Integration) is therefore depicted in Figure 1 as an ongoing line of activity throughout the life of the project. Our action research stance meant that we also designed in three cycles of research: (1) investigation; (2) design, contract, and commission urine diversion toilets; and (3) operate, monitor, evaluate, and decommission. The visual representation of the process that we developed both clarified our intent and captured the complexity of the concept in a way that could be readily shared with and readily comprehended by all the members of the team to ensure that everyone was clear about the conceptualization of the design and plans moving forward (see Figure 1).

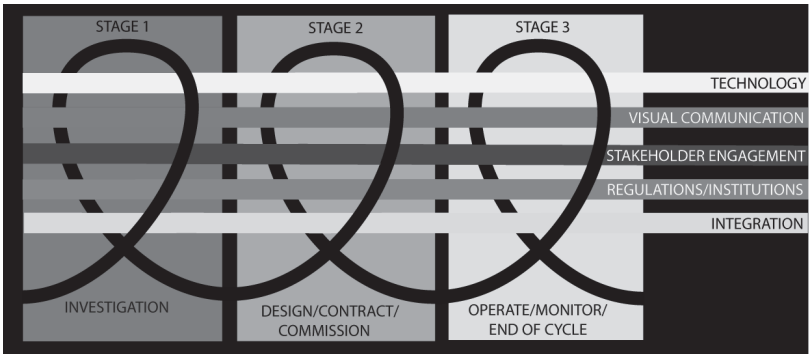

Figure 1. The first boundary object: a schematic of the conceptual approach for five strands of research spanning three action research cycles.

In line with Star's and Griesemer's (1989) concept of boundary objects, the schematic of the conceptual approach provided a rough structure for the research process that could be adapted to requirements as the project developed. We used the flexibility of the boundary object to create a space for learning. While we had clear and cogent plans on how we wanted the cycles of research to operate, we knew there were many, many unknowns.

In other words, we set out knowing and being explicit with all our team members about the fact that we would likely "skin our knees," so this colloquial terminology was part of the project's lexicon from the initial meeting that brought all the team members together. Rather than trying to obscure the high degree of change and emergence in the TD research process from our partners by attempting to make the process fit conventional expectations of research, we deliberately sought to construct an environment where our partners could experientially learn about the potential value of other ways of doing research. We were thus enabling our partners to expect and accept that emergent learnings could and should influence the direction of the project. In reality the project ran very differently from our plan: The small loops in Figure 2 each indicate a small cycle of initially unplanned action research that became necessary as the project progressed, and that changed the direction of our efforts (Dick, 2001).

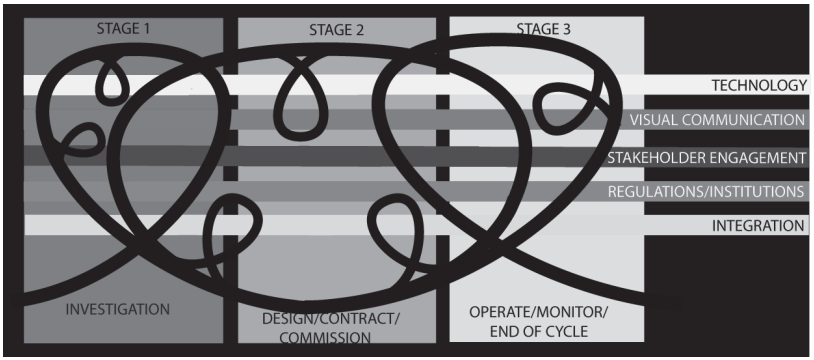

Figure 2. Schematic of the actual conceptual approach. The flexibility of the boundary object allowed us to adapt the representation of the methodological framework according to how the project unfolded in terms of action research cycles and subcycles (Mitchell, Fam, & Abeysuriya, 2013).

Another boundary object was an artefact that enabled the partners to position themselves in the process of the project (Figure 3). The systems diagram below brought together all the components of a new UD system as well as all the strands of research to help identify everyone's contribution and the connections between components of the system.

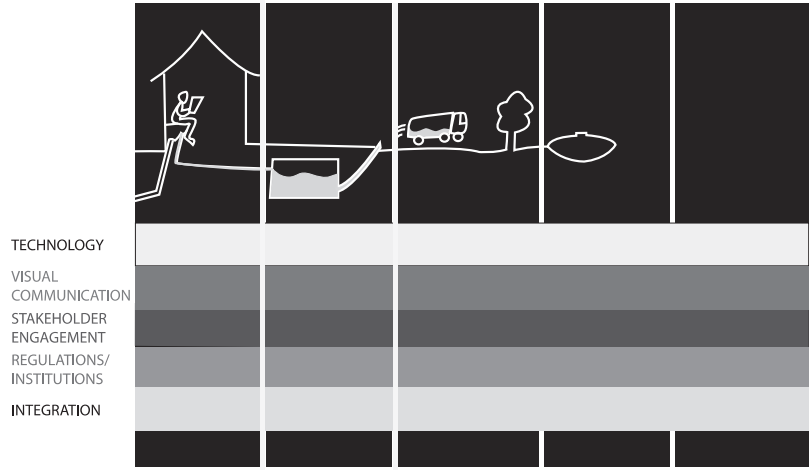

Figure 3. System diagram of the UD System (Mitchell et al., 2013).

Concept/Collaborative Learning: What activities have fostered collaborative learning and new hybrid expertise among the individuals and the entire team?

As elaborated above, the flexible methodological framework allowed creating a space for collaborative, or, as we framed it in our project, social learning from the beginning of the project. An unforeseen mode of interaction emerged in the form of writing as learning. Although its potential had not been recognized in the early stages of the project, collaborative writing proved to be important not only as a research contribution and an academic output but also as a mode of learning. Over the two years of the project, five academic conference papers were written across fields of systems thinking, design education, and transition management, and three academic journal papers were submitted in the areas of systems thinking, design studies, and transdisciplinary collaboration involving both industry and academic contributors. Cross-disciplinary coauthors commented on the process of writing as a mode of social learning with one industry partner highlighting that "in working with purely agricultural scientists… [writing together in the project] stretched my imagination a bit and made me think a little bit differently in how we approach the issue [of trialling a new system]." The opportunity to utilize academic writing as a means to the end of interdisciplinary learning was enhanced by the fact that half of the members of the project team

were academics from diverse disciplinary backgrounds. Industry partners also became productively involved in collaborative writing through interaction with academic partners.

Concept/Leadership: What leadership and management strategies have enhanced the prospect for communication and collaboration?

The UTS trial was designed to facilitate participatory leadership through actively engaging members of the project team in co-creating a community centered on the project. To deepen the engagement of, and therefore potential for meaning-making by, the team members, we created a largely horizontal structure of leadership, anchored in the experience and expertise of all the project participants. Although some leadership responsibilities did rest with individuals, as, for example, managing grant budgets and delivering grant outcomes, which were the responsibility of the Project Director, all participants were given the opportunity to make decisions about the direction of the project as well as develop and lead areas of research that were both important to individuals and beneficial to the project as a whole.

Empirical evidence from the UTS trial highlights the challenges and benefits of successfully implementing alternative models of leadership in practice. Supporting participants to take an active role in community-oriented leadership requires a facilitative rather than a directive approach. Facilitators are in effect serving a community at the same time as managing it. In community-oriented leadership, facilitators need to ensure that processes are in place to enable community members to improve their collective capability and contribute to learning in the process (Lank, Randell-Khan, Rosenbaum, & Tate, 2008). In the UTS trial, this involved designing strategies to engage and re-engage members in decision making and action, keeping the community energized, focused and interactive, and at times holding participants accountable. As a community is not a static entity, the facilitating role was dynamic, defined by the Project Director as "akin to herding" (Fam, 2017). It requires continually monitoring and evaluating the context in which members interact with each other and being respectfully responsive to challenges affecting members active in the project. In the UTS trial, this was achieved through the combination of weekly reflection on the project's development by core facilitating members, monthly meetings for those involved in each of the research strands, and whole group meetings every 4 to 6 months (Fam, 2017).

3b. The Swiss Case

The second project we analyzed for this article is called "Transdisciplinary Integration for Sustainable Urban Water Management in Switzerland." Urban water and wastewater management (hereafter called "water management") in Switzerland has gradually evolved over the last two centuries. Today, urban water management faces several challenges, including rehabilitation of aging infrastructure and adaptation to climate variability and demographic change. Meeting such challenges requires the transdisciplinary integration of disparate bodies of knowledge from both research and practice in order to understand the complexity, ambiguity, and uncertainty of such challenges and to develop and implement potential solutions. The synthesis project on Sustainable Urban Water Management in Switzerland (TS 3) aimed at meeting the challenges by integrating existing knowledge pertinent to urban water management in Switzerland. Funded by the Swiss National Science Foundation (SNSF), the project was carried out between 2012 and 2014 within the National Research Program on Sustainable Water Management (NRP 61). The project built on both knowledge delivered by seven (out of 16) individual NRP 61 projects (carried out between 2010 and 2013) and expertise provided by 36 key actors from both research and practice (see Table 3). Transdisciplinary integration within the synthesis project was systematically reflected in the associated NRP 61 research project headed by the leader of TS 3.

Concept/Boundary Work: What forms of boundary work are evident, factoring in the range of interdisciplinary, interprofessional, interactive, and transdisciplinary approaches?

The synthesis project involved (a) a core team, responsible for leading transdisciplinary integration within TS 3 and authoring the final synthesis report (Hoffmann, Hunkeler, & Maurer, 2014), (b) a steering committee, (c) an advisory board, and (d) a management office set up by the NRP 61, as well as (e) scientific experts from within and/or outside NRP 61 and (f) practice experts from different sectors (water supply, wastewater treatment) and decision levels (federal, cantonal, municipal). Table 3 summarizes the composition of the different actor groups involved in TS 3 (Hoffmann, Pohl, & Hering, 2017a).

Table 3
Actor groups involved in the Swiss project.

Actor group	**Involved disciplines or sectors, respectively**
Core team	3 researchers in the fields of environmental science, environmental engineering, and hydrogeology
Steering committee	6 internationally acknowledged experts in the fields of environmental engineering, aquatic ecology, environmental economics, hydrology, meteorology, and geophysics
Advisory board	10 key stakeholders from the Swiss Water Sector representing the national council (2), the federal office for the environment (1), cantonal authorities (3), NGOs (1), and trade associations, including the Swiss Water Association (1), the Swiss Gas & Water Industry Association (1), and the Swiss Water Management Association (1)
Management office	3 managers, including the SNSF program manager, the implementation officer, and the president of the steering committee
Research experts	7 researchers in the fields of environmental sciences, decision analysis, hydrogeology, hydrology, water chemistry, and limnology
Practice experts	7 key stakeholders representing the federal office for the environment (3), cantonal authorities (4), municipal authorities (1), consulting companies (1), water supply companies (2), the stakeholder network of Swiss Water Management (1), and trade associations, including the Swiss Water Association (1), the Swiss Gas & Water Industry Association (1), and Communal Infrastructure (1)
Total	36 experts from both research and practice

The boundaries that had to be worked on included

a) boundaries between different disciplines;
b) boundaries between those mandating, steering, advising on, and carrying out the research;
c) boundaries between different research projects;
d) boundaries between academics and stakeholders in society;
e) boundaries between different professions;
f) boundaries between different governmental levels.

Besides b) and c) these boundaries are all explicitly mentioned in the framework for analysis of boundary work. The boundaries listed as b) and c) point out further boundaries that necessitated work within the structure of the re-

search program NRP 61, be it between different research projects or different actor groups involved in mandating, steering, advising on, and carrying out research.

In order to work across boundaries, the core team worked together with the group of experts from research to define a number of key questions (Table 4) related to three types of knowledge relevant for urban water management in Switzerland (Hoffmann, 2016; Hoffmann, Pohl, & Hering, 2017b).

Table 4
Questions used to work across boundaries.

Knowledge type	**Integrative questions**
Systems knowledge	What are current and future challenges to urban water management in Switzerland? What causal links underlie these challenges?
Target knowledge	What are social, ecological, and economic targets of sustainable urban water management in Switzerland?
Transformation knowledge	What are options for action toward sustainable urban water management? What are the consequences of these options for action?

At the same time, the core team determined the need to develop a suitable method for integrating the different types of knowledge in a coherent and consistent way. Following Giupponi (2007), the team combined key elements of system analysis and multi-criteria decision analysis to structure and systematize the very heterogeneous research results provided by the seven individual research projects, ranging from the availability and quality of surface and groundwater resources *(systems knowledge)* to strategic planning of urban water infrastructure *(target knowledge)*. Based on the integrated results, the team generated new *transformation knowledge* targeted to the specific needs of federal, cantonal, and municipal authorities, water and wastewater companies, stakeholder networks, and trade associations (Hoffmann, 2016). Combining key elements of system analysis and multi-criteria decision analysis allowed for crossing the boundaries between different disciplines and projects; it also allowed for linking and relating the research results of such projects to the three types of knowledge and positioning them in the broader context of urban water management in Switzerland.

Concept/Leadership: What leadership and management strategies have enhanced the prospects for communication and collaboration?

The core team (see Table 3) took the lead in TS 3. The core team mainly employed two strategies to enable knowledge integration throughout the synthesis process to help all involved to cross the boundaries between different disciplines, projects, professions, and decision levels, and also between those mandating, steering, advising on, and carrying out research (Hoffmann et al., 2017b; Rossini & Porter, 1979). These two strategies were (a) common group learning, where integration of research results provided by the individual NRP 61 projects took place within the group of experts from research and/or practice working as a whole, and (b) integration by the core team, where integration of research results was handled by the core team, who interacted bilaterally with experts from research and practice to link and relate the results. Both integration strategies were employed iteratively with multiple loops within and between the involved disciplines, projects, and professions and across those mandating, steering, advising on, and carrying out research. The final results of this iterative integration were validated in consultation with the NRP 61 steering committee, the advisory board, and 25 experts to ensure not only their reliability and credibility, but also their relevance for research and practice (Hoffmann et al., 2017b).

By applying these strategies, the core team adopted two main roles throughout the synthesis process. In accordance with a typology introduced by Wieser, Brechelmacher, and Schendl (2014), in some stages the core team acted collectively as a facilitator fostering fruitful exchange with the NRP 61 steering committee, the advisory board, and the management team as well as with experts from both research and practice to, for instance, formulate sustainable targets for urban water and wastewater management, define potential options for actions, and assess the potential of such options to achieve those targets (Hoffmann et al., 2017b). In some stages, the core team shifted its role and acted collectively as a collaborator, engaging in bilateral discussions with experts from research and practice to, for instance, identify key challenges to urban water and wastewater management in Switzerland, analyze their causal relationships, and assess the impact of different options for actions on such challenges (Hoffmann et al., 2014).

Leading TS3 involved several challenges related to bridging the boundaries described above. Some challenges related to the synthesis process itself, for example, balancing competing demands of different actor groups (e.g. the steering committee, the advisory board, the management office, and experts from research and practice), as well as structuring, systematizing, prioritizing,

and synthesizing very heterogenous results from different research projects. Some other challenges related to the overall framework conditions of the synthesis process, including, for instance, the availability of research results and expert knowledge or the consolidation of final synthesis results (Hoffmann et al., 2017a). The various challenges triggered individual and collaborative learning processes as described below.

Concept/Collaborative Learning: What activities have fostered collaborative learning and new hybrid expertise among the individuals and the entire team?

Individual and collaborative learning was fostered by the associated research project on transdisciplinary integration. That research investigated transdisciplinary (knowledge) integration in TS 3, and also in three other synthesis projects carried out between 2012 and 2014 (TS 1, TS 2, and TS 4). The overlapping timeframes of the four synthesis projects together with the associated research conducted between 2013 and 2014 enabled a process of learning at different levels (see Hoffmann et al., 2017b):

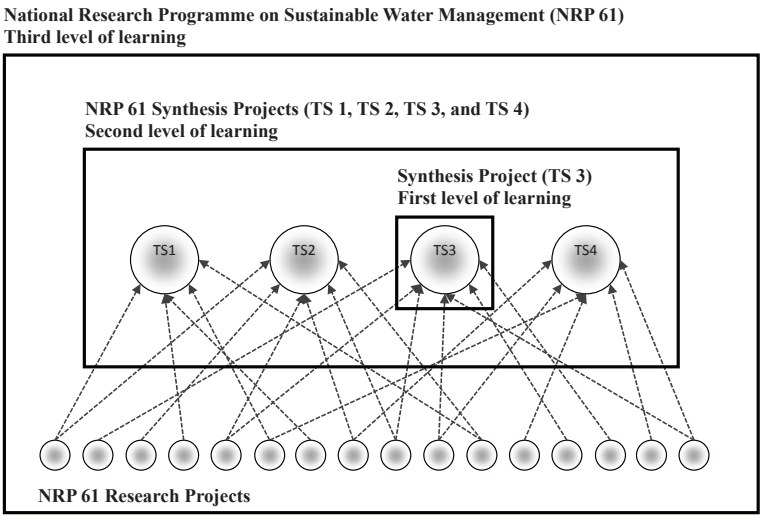

Figure 4 is a schematic illustration of the National Research Programme on Sustainable Water Management (NRP 61) carried out between 2010 and 2014, including 16 individual research projects (2010-2013) and 4 thematic synthesis projects (2012-2014), and the three levels at which learning occurred: at the level of the TS 3 synthesis project, at the level of all four synthesis projects (TS1, TS2, TS3, and TS4), and at the program level.

1. At the level of TS 3, the core team and the group of research experts started reflecting on the appropriate combination of methods and procedures for the integration of results from different disciplines and fields resulting in adaptations of methods and procedures in the course of the TS 3 synthesis process.
2. At the level of all four synthesis projects, a process of mutual learning started among the core teams of all the synthesis projects, (a) reflecting on the advantages and disadvantages of different approaches, (b) discussing challenges of transdisciplinary integration at different stages of the synthesis processes, and (c) formulating recommendations for future synthesis processes.
3. At the program level, the SNSF invited the leader of the TS 3 core team to present and discuss the results of the associated research on transdisciplinary integration at the annual conference of its Programme Division. The discussion led to the incorporation of the recommendations derived from that research into internal SNSF documents and guidelines supporting future synthesis processes in NRPs.

4. Discussion

Here we discuss our experiences with Klein's conceptual framework with two ends in mind: a) to explore and assess the heuristic value of the framework, that is, how it has improved our conceptualizations of boundary work in the two projects and b) to evaluate the framework itself, i.e. whether some of the seven concepts suggested in the framework are hard to work with as is and should be further developed.

Within the Australian project, the framework has provided a way to retrospectively reflect on the subcultures involved – which primarily involved industry and academic partners – and the unique expectations of academic involvement in TDR collaborations that needed to be addressed in providing incentives for academic partners. What has come to the fore in analyzing the case study against the framework is that the expertise of the team members significantly influenced the kinds of boundary objects produced. For example, the project manager's background as a visual communicator/designer meant that the technologies and products functioning as boundary objects were visually oriented (see Figures 1, 2, 3). The core project team did not explicitly set out to identify or manage boundaries – rather, our objective was to bring diverse interests together through generating shared visions and

intents, leading to mutually beneficial exchange between strands of research and teaching activities. Had the focus been on boundaries, we wonder what we would have done differently and whether the outcomes might have been richer (because we might have identified obstacles earlier in the project) or poorer (because we might have invested energy in what kept us separate, rather than in how we could better come together).

As regards the Swiss case, the framework allowed for reflecting *ex post* on the various boundaries that had to be worked on within the structure of NRP 61 (including boundaries between those mandating, steering, advising on, and carrying out research and between different research projects) to integrate knowledge and elaborate the final synthesis report. The framework was particularly helpful in analyzing different integration strategies that the TS3 core team employed to enhance communication and collaboration and in reflecting on individual and collaborative learning processes. It is a further merit of this framework that it allows those using it to explicitly address the issues of leadership and learning that are often neglected when analyzing boundary work and boundary crossing in interdisciplinary and transdisciplinary projects.

Looking at the framework in general and reviewing the experiences with both cases, we have concluded that the framework and the seven concepts involved are easy to understand and use. The only concept we did not use in either case analysis was *Interlanguages*. A reason might be that the project collaborations we analyzed were relatively short term, not allowing the time required for those engaged in a project to develop new social and cognitive communities with their own interlanguages. With regard to the other concepts (see Table 1), we gained the following insights:

- *Boundary Work*: For large collaborative projects, like NRP 61, the boundaries and the boundary work within the program structure have to be included in an analysis. These are boundaries between sub-projects as well as boundaries between those who mandate, steer, advise on, and carry out the research.
- *Subcultures*: Tables summarizing the subcultures involved are rather common in recent papers on interdisciplinary or transdisciplinary projects. What is less common is to elaborate their differences and their basis for exchanges, the latter being rather difficult to understand.
- *Expertise*: When Collins and Evans (2002) distinguished contributory from interactional expertise, they were not thinking of an expert facilitating such an exchange or trading of expertise. In our understanding, this role is key in order to further develop collab-

orative projects. In her conceptual framework, Klein mentions the "boundary spanner" under collaborative learning (concept 6). We would like to strengthen this idea by explicitly adding "facilitating expertise" as a further type of necessary expertise to concept 3.

- *Boundary Objects*: In the Australian project we found not one but several boundary objects, each being a useful bridge at a different stage of the project. Also, we found the transdisciplinary research approach itself to be an important boundary object, specifically early in the project. Furthermore, we learned that some of the boundary objects were very flexible and could be adapted, like the research approach (Figures 1 and 2), and others were rather stable, like the system diagram (Figure 3). This observation raises the question under what conditions stable boundary objects can be useful for collaboration, too.
- *Collaborative Learning*: We found three means that enable collaborative learning: a) a flexible methodological framework, b) joint writing, and c) an associated research project feeding back preliminary results.
- *Leadership*: We found that leadership might require that the same persons assume different roles at different moments of collaboration, acting, for example, as the facilitator (with facilitating expertise) as well as the collaborator (with contributory expertise) engaging in bilateral discussions with experts from research and practice. We assume further roles are needed if persons are to successfully lead and manage boundary work. The framework should therefore ask not only for leadership strategies, but also for clarification of roles and responsibilities among the participants.

5. Conclusion

What, then, have we learned from using Julie Thompson Klein's conceptual framework to analyze boundary work in two of our projects? First, we have learned how the concepts involved – like glasses – help (or force) the user to see and analyze interdisciplinary and transdisciplinary projects in a specific way. When analyzing projects using the concepts of boundary work and boundary crossing, we first looked for differences between groups, be it researchers from different disciplines or actors from different sectors of society. Only in a second step did we focus on boundary objects and on how

boundaries are crossed. For some of those working in interdisciplinary and transdisciplinary projects, this process might seem counterintuitive, because IDR and TDR are about integration and hence about what the participants share rather than about what makes them different. For others working in the field, looking for differences seems a logical way to begin any interdisciplinary or transdisciplinary project: to acknowledge differences in order to be able to build on them for collaboration. So, the framework sets a clear focus on boundaries, a focus that might not be appreciated by everyone.

Second, we learned that we did not find concepts we consider key in interdisciplinary and transdisciplinary projects mirrored in the concepts of boundary work and boundary spanning as currently expressed. Those key concepts are facilitating expertise and facilitating leadership. Whereas some scholars might look at interdisciplinary and transdisciplinary projects from an observer's position, seeing project participants interacting around a boundary object, we who have been participants in such projects realize we have often had to act to make this interaction happen. We consider that this role of the facilitator or boundary spanner who has relevant expertise is not yet included in the framework sufficiently. Some further conceptual work lies ahead of us.

Finally, we learned once again how fruitful and inspiring it can be to use concepts from other fields – well prepared and ready for use in the form of a conceptual framework – to reflect on interdisciplinary and transdisciplinary collaborations, regardless of whether the reflections evolved in the way originally intended by those who developed the concepts and organized them in a framework.

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