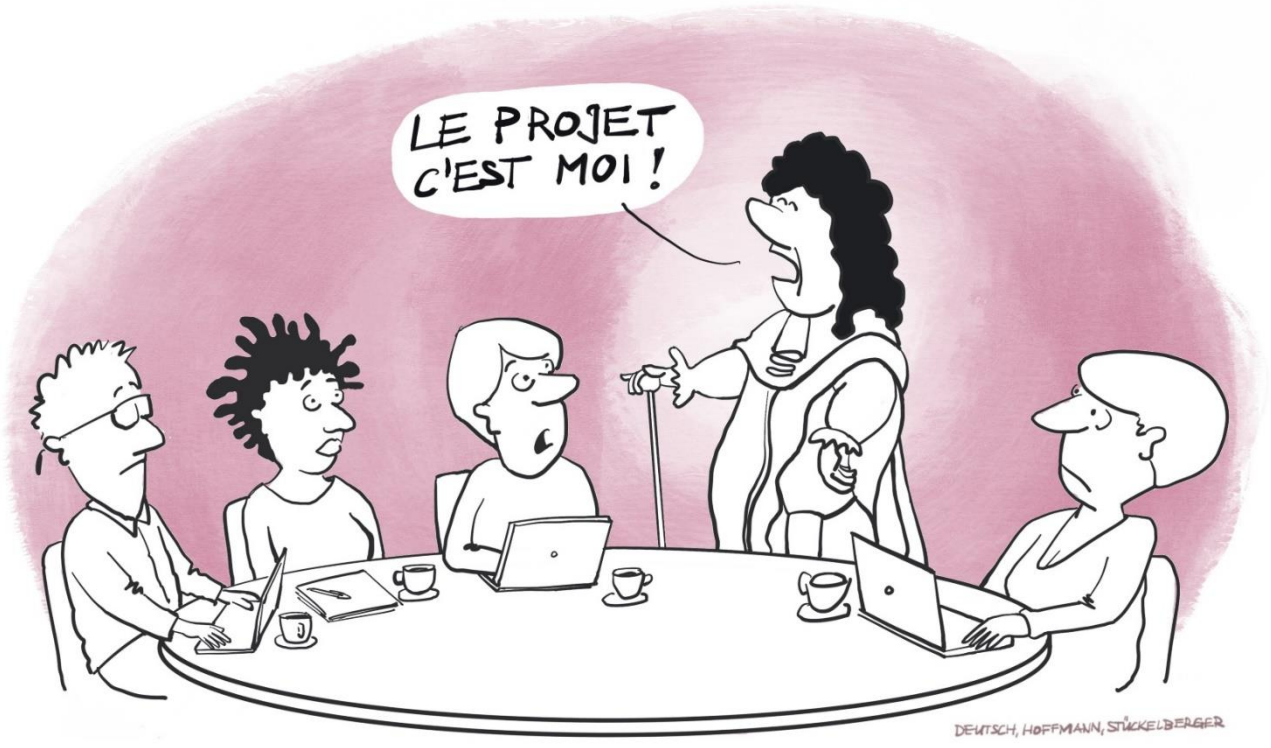
DISS. ETH. NO. 30301

Practicing integration in inter- and transdisciplinary research:

The role of enabling conditions and integrative leadership

Lisa Deutsch



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Practicing integration in inter- and transdisciplinary research:

The role of enabling conditions and integrative leadership

A thesis submitted to attain the degree of

DOCTOR OF SCIENCES

(Dr.sc. ETH Zurich)

presented by

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2024

Abstract

Given the complexity of contemporary societal challenges such as climate change, sustainability transformations and pandemics, the question of how these challenges can be adequately addressed has become increasingly urgent in recent years. In the highly differentiated societies of the 21st century, there is generally no shortage of experts who can make a valuable contribution to addressing these problems. However, what tends to be lacking is a meaningful integration of these individual perspectives across disciplinary boundaries (interdisciplinarity) as well as the integration of knowledge from science, policy and practice (transdisciplinarity) in order to avoid a one-sided understanding of and solution to the aforementioned challenges. For this reason, more and more inter- and transdisciplinary research programs are being set up to address societally relevant issues by bundling several projects under one roof and involving a large number of different disciplines and stakeholders. However, this integration does not take place automatically, but must be proactively encouraged, fostered and led. This dissertation aims to contribute to the theoretical understanding as well as the practical implementation of inter- and transdisciplinary (ITD) integration in research programs and projects by embracing three research foci: (a) the role of conditions under which ITD integration takes place (*structures*), (b) the role of integrative leadership to advance ITD integration processes (*agency*), and (c) the role of integrative methods to facilitate ITD integration (*means*).

These three key areas were studied as part of qualitative accompanying research in three ITD research initiatives between 2020 and 2023 in Switzerland: (1) the ITD research program "Extremes" at WSL (Swiss Federal Institute for Forest, Snow and Landscape Research), (2) the cross-sectoral network NCCS (National Center for Climate Services, hosted by the Federal Office of Meteorology and Climatology MeteoSwiss) and its ITD research program "NCCS-Impacts" and (3) the ITD program "Wings" (Water and sanitation innovations for non-grid solutions) at Eawag (Swiss Federal Institute of Aquatic Science and Technology). All research programs and the network had a co-leadership structure and were composed of a core team (around 25 people) and an extended program team (up to 100 participants). The research process of this thesis consisted of triangulating qualitative methods, namely semi-structured interviews, participant observation, focus groups and reflection diaries, and was embedded in a critical realist meta-framework. The cumulative doctoral thesis encompasses three scientific articles, each of which focuses on one of the aforementioned key areas (*structures, agency, means*), but also includes partial aspects of the other key areas or shows interlinkages between them.

First, this thesis contributes to the theoretical and empirical understanding of enabling and hindering conditions for ITD integration, and identifies scope for action to ensure more favorable conditions. In doing so, it distinguishes conditions at different structural levels, i.e. the individual, team, program, institutional and socio-political level, as well as different actor groups, i.e. individual team members, program leaders, directors of (research) institutions, funders and science policy-makers. The developed structure-agency model links the aforementioned structural levels with the different actor groups, and

shows who (actor group) can potentially do what and how (action) at which level (structures) in order to create more favorable conditions for ITD integration.

Second, the present work further contributes to the conceptualization and operationalization of integrative leadership in ITD research programs. Integrative leadership can be understood as an interplay of supportive and creative contributions stemming from both team members and the program leaders. Integrative leadership therefore means more than simply taking on a facilitation role, but also includes an intellectual contribution from the leaders themselves. This thesis identifies at least six core leadership challenges that program leaders face and potentially need to address if they want to advance integration in a larger program team (i.e. in the order of 25 to 100 participants) from different disciplines and societal sectors. It also makes concrete suggestions as to which strategies have proven successful from the perspective of the program leaders and which resources should be guaranteed for what kind of leadership tasks for ITD research programs of a similar size in the future.

Third, this doctoral thesis adapted an integrative method, namely "Theory of Change", to an ITD research program context and tested it from a leadership perspective within the research program Wings at Eawag. The role of integrative methods and boundary objects for ITD integration is repeatedly emphasized in the literature on inter- and transdisciplinarity. In recent decades, a variety of methodological toolkits have been developed to facilitate and practically implement ITD integration. This thesis presents empirical insights into the application of the method "Theory of Change" in an ITD research program context for advancing integration, reflects on the associated challenges and discusses implications for integrative leadership as well as necessary conditions for integration in ITD research programs.

Overall, this thesis intends to bridge theory and practice as well as the abstract and the empirical by contributing to the conceptualization of enabling conditions, integrative leadership and methods for ITD integration, and by providing concrete empirical and action-oriented insights for enabling integration in practice. The results presented here can potentially be useful for all those actors who want to support and ensure the success of ITD projects and programs and their contribution to addressing societal problems in the future.

Zusammenfassung

Angesichts aktueller komplexer gesellschaftlicher Herausforderungen wie dem Klimawandel, Nachhaltigkeitstransformationen oder Pandemien, wurde in den letzten Jahren und Jahrzehnten die Frage immer drängender wie diesen Problemstellungen in angemessener Weise begegnet werden kann. In hoch differenzierten Gesellschaften des 21. Jahrhunderts fehlt es in der Regel nicht an Expert:innen, die zum Umgang oder der Lösung dieser Probleme einen wertvollen Beitrag leisten können. Woran es jedoch tendenziell fehlt ist eine sinnvolle Integration der einzelnen Perspektiven über disziplinäre Fachgrenzen hinweg (Interdisziplinarität) als auch die Integration von Perspektiven aus Wissenschaft, Politik und Praxis (Transdisziplinarität), um ein einseitiges Problemverständnis als auch –lösung zu vermeiden. Aus diesem Grund werden vermehrt inter- und transdisziplinäre Forschungsprogramme ins Leben gerufen, um gesellschaftlich relevante Fragen mithilfe mehrere Projekte unter einem Dach sowie unter Einbezug einer Vielzahl von Disziplinen und Stakeholdern zu behandeln. Diese Integration findet allerdings nicht automatisch statt, sondern muss proaktiv gefördert, unterstützt und geleitet werden. Die vorliegende Doktorarbeit möchte einen Beitrag zum theoretischen Verständnis als auch zur praktischen Umsetzung von inter- und transdisziplinären (ITD) Integration in Forschungsprogrammen, aber auch Einzelprojekten leisten, indem sie sich auf drei Schwerpunkte konzentriert: (a) die Rolle von Rahmenbedingungen, unter welchen ITD Integration stattfindet (*Strukturen*), (b) die Rolle von integrativer Führung in der Leitung von ITD Integrationsprozessen (*Handeln*), und (c) die Rolle von integrativen Methoden zur Förderung von ITD Integration (*Mittel*).

Diese drei Schwerpunkte wurden im Rahmen einer qualitativen Begleitforschung in drei ITD Forschungsprogrammen bzw. einem Netzwerk zwischen 2020 und 2023 in der Schweiz untersucht: (1) das ITD Forschungsprogramm «Extremes» an der WSL (Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft), (2) das sektorenübergreifende Netzwerk NCCS (Nationales Zentrum für Klimadienstleistungen, Geschäftsstelle: Bundesamt MeteoSchweiz) und sein ITD Forschungsprogramm «NCCS-Impacts» sowie (3) das ITD Programm «Wings» (Wasser- und Abwasserinnovationen für netzunabhängige Lösungen) an der Eawag (Eidgenössische Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz). Alle Forschungsprogramme sowie das Netzwerk wurden in Form einer Co-Leitungsstruktur geführt und bestanden aus einem Kernteam (etwa 25 Personen) und einem erweiterten Programmteam (bis zu 100 Personen). Der Begleitforschungsprozess bestand aus einer komplementären Anwendung von qualitativen Methoden, nämlich semi-strukturierten Interviews, teilnehmender Beobachtung, Fokusgruppen sowie Reflexionstagebüchern und war in einen kritisch realistischen Metarahmen eingebettet. Die kumulative Doktorarbeit besteht aus drei wissenschaftlichen Artikeln, die jeweils einen der genannten Schwerpunkte (*Strukturen, Handeln, Mittel*) als Fokus haben, allerdings auch Teilaspekte der anderen Schwerpunkte beinhalten oder Verbindungen dazu aufzeigen.

Zunächst leistet die Arbeit einen Beitrag zum theoretischen und empirischen Verständnis von förderlichen bzw. hinderlichen Rahmenbedingungen für ITD Integration, und präsentiert mögliche

Handlungsspielräume, um förderliche Rahmenbedingungen zu gewährleisten. Dabei unterscheidet sie Rahmenbedingungen auf verschiedenen strukturellen Ebenen, d.h. der individuellen, Team-, Programm-, Institutionen- und sozio-politischen Ebene, sowie verschiedenen Akteursgruppen, d.h. individuelle Teammitglieder, Programmleitende, Direktor:innen von (Forschungs-)Institutionen, Geldgeber:innen und wissenschaftspolitischen Entscheidungsträger:innen. Das präsentierte Modell verknüpft die genannten strukturellen Ebenen und Akteursgruppen miteinander und zeigt auf wer (Akteursgruppe) potenziell was und wie (Handlung) auf welcher Ebene (Strukturen) tun kann, um förderlichere Rahmenbedingungen für ITD Integration zu schaffen.

Zweitens, trägt die vorliegende Arbeit zur Konzeptualisierung und Operationalisierung von integrativer Führung in ITD Forschungsprogrammen bei. Integrative Führung kann als ein Zusammenspiel von unterstützenden und kreativen Beiträgen verstanden werden, die sowohl von den Teammitgliedern als auch den Leitenden selbst stammen. Integrativ führen bedeutet also mehr als eine reine Moderationsrolle einzunehmen, sondern beinhaltet auch einen eigenen intellektuellen Beitrag von Seiten der Leitenden. Die Arbeit identifiziert mindestens sechs Führungsherausforderungen, die Programmleitenden begegnen und potenziell adressieren müssen, wenn sie Integration in einem Kernteam von etwa 25 Personen, sowie einem erweiterten Programmteam von bis zu 100 Personen, die aus unterschiedlichen Disziplinen und Sektoren stammen, vorantreiben wollen. Dabei macht die Arbeit auch konkrete Vorschläge welche Strategien sich aus Perspektive der Programmleitung bewährt haben und welche Ressourcen für welche Bandbreite von Führungsaufgaben in Zukunft für ITD Forschungsprogramme von ähnlicher Grösse gewährleistet werden sollten.

Drittens, hat diese Doktorarbeit eine integrative Methode, nämlich «Theory of Change» an einen ITD Forschungsprogrammkontext adaptiert und aus Leitungsperspektive im Forschungsprogramm Wings an der Eawag getestet. Die Rolle von integrativen Methoden sowie «boundary objects» für ITD Integration wird in der Literatur zu Inter- und Transdisziplinarität immer wieder hervorgehoben. In den letzten Jahrzehnten wurden deshalb eine Vielzahl von Methodentoolkits entwickelt, um ITD Integration zu erleichtern, sowie praktisch umzusetzen. Die vorliegende Arbeit präsentiert empirische Einsichten in die Anwendung von «Theory of Change» in einem ITD Forschungsprogrammkontext, reflektiert die damit verbundenen Herausforderungen und diskutiert Implikationen für die integrative Führung als auch notwendige Rahmenbedingungen für Integration in ITD Forschungsprogrammen.

Insgesamt, spannt die Doktorarbeit einen Bogen zwischen Theorie und Praxis, dem Abstrakten und dem Empirischen indem sie sowohl einen Beitrag zur Konzeptualisierung von Rahmenbedingungen, integrativer Führung und integrativen Methoden für ITD Integration leistet, als auch konkrete empirische und handlungsorientierte Einsichten aufzeigt. Die vorliegenden Ergebnisse können potenziell für all jene Akteure nützlich sein, die das Gelingen von ITD Projekten und Programmen und deren Beitrag zur Lösung gesellschaftlicher Problemstellungen in der Zukunft unterstützen bzw. sicherstellen möchten.

Acknowledgements

First, I want to thank my supervisor and ITD research group leader, Sabine Hoffmann, for her continuous support, her contagious passion for inter- and transdisciplinary research, and her enthusiasm and courage to push the boundaries of the status quo. During my job interview for a scientific assistant position with her in February 2019, I voiced the wish to pursue a PhD and from day one, she subsequently made everything possible to realize this wish as soon as possible. While supporting her in the leadership of the inter- and transdisciplinary research program Wings, she strongly involved me in the design and decision-making processes of the program and thereby allowed me to experience co-leadership from which early-career researchers are often excluded until often quite late in their career. Her perseverance and creative constructive approach to difficult situations has deeply impressed me and I consider myself fortunate to be able to say that I learnt much more from her than just sound scientific work.

I equally thank my supervisors David Bresch and Christian Pohl, and their respective research groups WCR and TdLab at ETH Zurich. I always felt very welcomed by them and all research group members. I was always included in research group internal events such as retreats, excursions and informal scientific exchanges and benefitted a lot from meeting so many open-minded people from diverse backgrounds and knowledge fields. I want to thank David for always encouraging me to experiment and for strongly supporting me to try something new, and Christian for always providing precise and quick advice on 'integration-matters' and guiding me through the history and community of inter- and transdisciplinary studies. I consider myself to have been very lucky with the overall composition of my PhD committee (Sabine, David, Christian), which turned out to consist of three very different, yet very pleasant and complementary personalities, who enriched my scientific work and overall PhD time substantially. I am further very pleased to have Merritt Polk on my committee, who is not only a great expert in the field of inter- and transdisciplinary studies, but a genuine supporter of early-career researchers.

I am very grateful to the participants of the three inter- and transdisciplinary research programs Wings (Eawag), Extremes (WSL) and the network NCCS (MeteoSwiss and related institutions), who constituted the three case studies of this research project. Without sharing their experiences, thoughts and concerns about inter- and transdisciplinary integration so openly, this project would not have been possible. It was a real pleasure to work with the six leaders of the respective programs and network, namely Sabine Hoffmann and Christian Zurbrügg, Astrid Björnsen and Niklaus Zimmermann, Michiko Hama and Andreas Fischer. Without any doubt, they constituted one of the cornerstones of this thesis and I am very thankful for the time and efforts they invested in this research project throughout the last few years. I am also very grateful to the Eawag Directorate for seeing potential in this research project and providing discretionary funding in order to make this project possible.

Several people have enriched my time at Eawag and my PhD phase, in particular my research group "Inter- and Transdisciplinarity" (ITD), namely Donata Dettwiler, Benjamin Hofmann, Hanna Salomon and Jana Thierfelder, with whom I enjoyed working together very much and I look forward to further joint work in the future – all of them are brilliant minds and amiable personalities. I want to thank my colleagues at the Environmental Social Sciences department at Eawag for very nice lunch and hallway conversations throughout the last few years, in particular Alice Aubert, Nadja Contzen, Julie Dölker, Fabian Dvorak, Josianne Kollmann, Liliane Manny and Milena Wiget, who have been part of my PhD process. I further want to thank all the members of Wings, with whom I have collaborated very closely over the past five years and from whom I have learnt a lot. I am very proud of the work that was done in particular with the Wings early-career researchers Philipp Beutler, Giuseppe Congiu, Carina Doll, Jonas Heiberg, Josianne Kollmann, Abishek S. Narayan, Katrin Pakizer and George Wainaina.

Special thanks go to Andrew Clarke, Julian Dederke, Jonathan Gruber and Benjamin Hofmann for proofreading my thesis and providing very valuable feedback. The cartoon series presented in my thesis would not have been possible without the cartoonist Christof Stückelberger, who did an excellent job in creating humoristic scenes based on our scientific findings. Paul Donahue's feedback on the cartoons and his support in the creation of Wings synthesis outputs are likewise gratefully acknowledged.

Finally, yet importantly, I want to thank all my friends who have supported me throughout the last few years as well as my family, in particular my parents, who have always encouraged me to pursue my own path and supported me in all my endeavors, although studying sociology and moving to Mexico, Germany and later to Switzerland was maybe not their first choice for me. Special thanks go to Jonathan, who does not enjoy being extensively praised in public. For this reason, I will leave it at a simple "thank you", but I hope he knows how much his support means to me.

When looking at this long list of names, it becomes apparent that although research is often depicted as a lonely endeavor, actual practice looks very different. Solid and innovative research relies on fruitful collaborations and joint thinking with many different people from diverse backgrounds over time – hence this undertaking would hardly have been possible without them.

Table of contents

Abstract ... **4**
Zusammenfassung ... **6**
Acknowledgements ... **8**
List of tables ... **12**
List of figures ... **12**
1. Introduction ... **13**
2. Theoretical background and key concepts ... **16**
2.1. Disciplinary differentiation and inter- and transdisciplinary integration ... 16
2.2. Enabling integration: conditions, leadership and methods ... 18
3. Research questions and philosophical assumptions ... **22**
4. Research design ... **28**
4.1. Accompanying research and case studies ... 28
4.2. Methods and analysis ... 33
4.3. Positionality and role reflection ... 35
5. Creating favorable conditions for inter- and transdisciplinary integration – an analytical framework and empirical insights (article 1) ... **38**
5.1. Introduction ... 38
5.2. The ecosystem of inter- and transdisciplinary integration ... 39
5.3. An analytical framework for ITD integration: the interplay between structure and agency ... 42
5.4. Research design ... 43
5.5. Results ... 46
5.6. Implications and recommendations ... 55
5.7. Conclusion ... 58
6. Herding cats - Integrative leadership strategies in inter- and transdisciplinary research programs (article 2) ... **60**
6.1. Introduction ... 60
6.2. Research design: case studies, methods and role of authors ... 63
6.3. Results and discussion ... 68
6.4. Overall implications for integrative leadership in ITD programs ... 80
6.5. Conclusion ... 82
7. Leading inter- and transdisciplinary research: Lessons from applying theories of change to a strategic research program (article 3) ... **84**
7.1. Introduction ... 84
7.2. Case study & methods ... 86
7.3. ToC development process ... 89
7.4. Challenges and lessons learned ... 94
7.5. Conclusion and outlook ... 100
8. Action-oriented processes, outcomes and outputs ... **102**

9. Synthesis **105**
9.1. Contribution 1: A structure-agency perspective on ITD integration and scope for action 106
9.2. Contribution 2: Conceptualization and operationalization of 'integrative leadership' in ITD programs 109
9.3. Contribution 3: Testing and adapting 'theory of change' as an integrative method for leading ITD programs 112
9.4. Limitations and future research 114
10. Concluding remarks **117**
11. References **118**
Appendix **134**
A – Cartoons 134
B – Chapter five 139
C – Chapter seven 141
D – Interview guideline 143
E – Ethical approval 145

List of tables

(Shortened legends)

Table 1: Overview of the three research articles 25
Table 2: Overview of the three ITD research programs (case studies) in Switzerland 31
Table 3: Three types of accompanying research to research programs 32
Table 4: Overview of the methods employed and collected data 34
Table 5: Characteristics of the three Swiss case studies 44
Table 6: Recommendations for actions to enable integration 57
Table 7: Overview of the three studied ITD programs in Switzerland 64
Table 8: Composition, purposes and focus of the program and its pillars 88
Table 9: Two key recommendations according to actor group and structural level 108

List of figures

(Shortened legends)

Figure 1: Overall framework of the thesis 24
Figure 2: Overview and location of the three case studies Extremes, NCCS and Wings 29
Figure 3: A holistic view on ITD integration 42
Figure 4: Portfolio of tasks, responsibilities and contributions of integrative leadership 81
Figure 5: Wings Program Structure 87
Figure 6: ToC development process at project, pillar, and program level 90
Figure 7: Actor analysis 92
Figure 8: Generic ToC at pillar and program level developed within Wings 93
Figure 9: Example of a developed ToC on project level (forecasting) 141
Figure 10: Example of a developed ToC on pillar level (backcasting) 142

1. Introduction

More and more researchers concern themselves with inter- (ID) and transdisciplinary (TD) research approaches today (Thompson Klein, 2004; Vermeulen & Witjes, 2020). Some consider ID and TD research crucial for contributing to the alleviation of or solution to complex societal challenges such as sustainability problems (Augsburg, 2014; Hirsch Hadorn, Biber-Klemm, et al., 2008; Lang et al., 2012). Others are curiosity-driven and want to make use of the "creative tensions" existent between different disciplinary fields and types of expertise in order to identify novel and innovative questions pertaining to their own respective disciplines or across disciplines linked with their own fields (Cairns et al., 2020, p. 1719; Guimarães et al., 2019). Another driver constitutes the increasing perceived pressure to incorporate more ID and TD approaches in one's own research agenda as it has become more and more 'en vogue' (Cairns et al., 2020; Lawrence & Després, 2004) and funders have made it a core criterion in new funding schemes (Lindvig & Hillersdal, 2019). Irrespective of the reason, one is more and more faced with the question of what ID and TD approaches actually entail and how they can be put into practice.

In 1990, Julie Thompson Klein, one of the key scholars of the modern domain of inter- and transdisciplinary (ITD) studies, aptly noted that the concept of interdisciplinarity – and I add here also the concept of transdisciplinarity – are concepts of both widespread appeal as well as of widespread confusion (Klein, 1990, p. 11). Despite the extensive contributions of a wide range of scholars in the field of ITD studies since then, a certain confusion persists in the academic community and beyond given the existence of diverse understandings of these terms (Vienni-Baptista et al., 2022). Another reason for the conceptual disorientation is that ID and TD are sometimes employed without their meanings being defined in concrete terms (Klein, 1990). 'Multidisciplinarity', 'Interdisciplinarity' and 'Transdisciplinarity' are often used interchangeably, although they differ profoundly in their research approach. For instance, the mere presence of multiple disciplines in a research project does not yet make a project interdisciplinary. In order to distinguish these different research approaches, the concept of 'integration' becomes key.[1] Multidisciplinarity does not actively pursue integration (Klein 2010) and is therefore rather an accumulation of different disciplinary viewpoints on a common topic without making connections between them and thereby creating 'new' knowledge. The disciplinary researchers remain in their business-as-usual modus and do not extend or cross the boundaries of their theories, frameworks or methods (Holbrook, 2013).

By contrast, interdisciplinarity requires researchers to work in an integrative and interdependent manner from the very start and throughout the respective project or program (Defila & Di Giulio, 2015; Mauthner & Doucet, 2008). This entails iteratively engaging with each other, identifying connections

[1] Some scholars or practitioners from different fields use these terms in a completely different manner. I do not claim any right or wrong use of the terms, but stress the importance of clearly defining what they mean when using them as I will do in the following. I support the position of Vienni Baptista et al. (2023, p. 6) to "acknowledge plural understandings of ID and TD and permit them to coexist in research (and funding) environments".

and exploiting synergies between their efforts for the purpose of answering a complex question that cannot be answered by one discipline alone (O'Rourke et al., 2016; Pohl et al., 2021). The same integrative procedure applies to transdisciplinarity, with the crucial difference that the involved project parties extend beyond academia and include representatives from different societal spheres (e.g. practice, policy, civil society) in order to jointly work on a complex societal problem (ibid). One of the desired outcomes of TD research is what Helga Nowotny (1999) called 'socially robust knowledge', which is expected to help address, for instance, current sustainability challenges (Keitsch & Vermeulen, 2020). This represents a shift in the science-society contract from generating knowledge that is merely reliable within disciplinary boundaries to producing key insights for specific real-world problem contexts (Gibbons, 1999; Nowotny, 1999). This knowledge is then socially robust since it builds upon "the many heterogeneous factors, expectations, challenges and contestations which are now, wrongly, labelled non-scientific" (Nowotny, 1999, p. 16). A quarter century later, Kaiser and Gluckman (2023, p. 5) similarly make a case for ID and TD approaches and note in the most recent report for the International Science Council that "[s]cience needs to find and try new forms of research and partnership to ensure public trust, and to be a reliable input into societal decision-making and policy-making, while also continuing with traditional modes of enquiry."

Given this persistent push for ID and TD approaches in light of the urgency of complex societal challenges, the question remains how ID and TD integration can be effectively achieved. Many researchers report that although they would like to live up to the integrative ambition of their ID and TD proposals, they sometimes experience high levels of frustration given the manifold barriers they face during integration processes such as insufficient institutional support, unproductive conflicts between disciplines or lack of integration expertise within teams (Hoffmann, Deutsch, et al., 2022; Müller & Kaltenbrunner, 2019; Schuitema & D. Sintov, 2017; Ylijoki, 2022). They experience a discrepancy between the theory and practice of ID/TD (Defila & Di Giulio, 2015) or, differently formulated, between the increasing call for integration by funders, universities and research councils (Bruce et al., 2004; Ramadier, 2004) and the often unfavorable structures in place for making integration within academia and beyond happen in practice (Jahn et al., 2012; Vienni-Baptista & Thompson Klein, 2022). This discrepancy is the point of departure of this thesis.

Instead of merely adding to the long list of barriers, which are currently hindering ITD approaches, the motivation of this doctoral thesis is to look at the 'how-to' (Caniglia et al., 2021) of ID and TD integration, hence how integration can be enabled and strengthened in practice. For doing so, I decided to embrace three foci:

1. The role of conditions under which ITD integration takes place (*structures*)
2. The role of integrative leadership in integration processes (*agency*)
3. The role of integrative methods for facilitating integration processes (*means*)

These three foci (structures, agency, and means) are reflected in three research articles, which constitute the backbone of this cumulative thesis. The structure of my thesis is as follows: In chapter two, I first provide an overview of the theoretical background that informed my work. This means that I briefly discuss the core concepts of my thesis, which include *differentiation* and *integration*, *structures* and *agency*, *leadership* and *integrative methods*. Since I have discussed these concepts in more detail in the individual articles (see chapters five to seven), the aim of chapter two is to provide additional relevant background and to link these concepts with each other instead of elaborating on each of them in depth. In chapter three, I elaborate on my research questions, my overall framework and the underlying philosophical assumptions that informed my study. In chapter four, I provide an overview of my qualitative research adhering to an accompanying design, the respective case studies, methods and my role as accompanying researcher in the different case study contexts. Subsequently, the three respective research articles are presented in chapters five, six and seven. In chapter five, I embrace a system view on ITD integration by looking at the underlying conditions at different structural levels under which large ITD teams try to pursue integration. In chapter six, I specifically examine one actor group, namely those in charge of leading integration, often the ITD project or program leaders, and how they can enable ITD integration through integrative leadership practices. Finally, chapter seven focuses on the enabling power of a specific method, namely 'Theory of Change', for advancing integration. In the overall synthesis, I show that the implementation of integrative methods again depends on integrative leadership and is influenced by underlying conditions. The three foci are therefore interrelated and mutually inform each other. In all three research articles, I had the intention to generate action-oriented knowledge (Caniglia et al., 2021; Fazey et al., 2018), meaning that the research question asked and the analysis performed (see chapters three and four) were directed towards generating relevant knowledge oriented towards enabling integration processes in practice. Chapter eight then gives an overview of how I shared and processed my results in such a way as to make them accessible and actionable for other researchers and leaders of ID and TD initiatives. I further present how my accompanying research has contributed to several processes in the different case study contexts. Finally, in chapter nine I summarize the contributions of my thesis, discuss limitations and outline potential ways forward.

For the reason of simplicity, I mostly use first-person language throughout this thesis. However, I want to emphasize at this point that the three articles have been written in close collaboration with several co-authors from research and public administration, i.e. my PhD supervisors (article 1/chapter five), the leaders of the three ITD programs and case studies (article 2/chapter six) as well as international experts in the field of Theory of Change (article 3/chapter seven). Overall, I aim to contribute with this thesis to (1) creating more favorable conditions for integration, (2) supporting conscious, reflective and proactive leadership processes in ITD contexts and (3) in doing so, intend to contribute to the overall success of ITD research addressing societally relevant problems in the future.

2. Theoretical background and key concepts

Discussing inter- and transdisciplinary integration is inevitably linked to discussing disciplinary differentiation (Raab, 1998). Without disciplines and their respective boundaries, there would be nothing that needed to be crossed and integrated. For this reason, I will take a brief look at the history of disciplines, and the relationship between differentiation and integration in chapter 2.1. Furthermore, ID and TD integration processes do not take place in a vacuum. They are influenced by both contextual factors and the actions of the individuals involved in the ID/TD project or program (Ding et al., 2020) and the means employed in these contexts. For this reason, I will provide an overview of the literature on enabling and hindering conditions for integration, leadership and methods in chapter 2.2.

2.1. Disciplinary differentiation and inter- and transdisciplinary integration

According to Moran (2010, p. 2), there are two modern usages of the term 'discipline': the first usage refers to "a particular branch of learning or body of knowledge". This represents the common way of describing a more or less clearly defined specialized field in academia. Disciplines delimit what to study (research foci), how to study it (method), and what kind of knowledge and in what form (e.g. qualitative/quantitative, small-/large-scale data) is considered desirable (Jay et al., 2017, pp. 223-225). The other usage of discipline refers to "the maintenance of order and control amongst subordinated groups such as soldiers, prison inmates or school pupils, often through the threat of physical or other forms of punishment." (Moran, 2010, p. 2). Looking at these two usages together, also in academia new generations are to a certain extent 'disciplined', hence expected to comply with the rules of a specialized field in order to advance in it. At the same time, disciplines are not static; the way knowledge and disciplines are organized and differentiated is an on-going process (Stichweh, 2001).

Although central to academia's structure and reward system today, the modern system of disciplines is a product reaching back only to the 19th century (Klein, 1990). However, throughout history there have always been attempts to find a way of organizing and forming a hierarchy of knowledge, while also striving for a certain 'unity of knowledge' at the same time (ibid). Discussions about how to structure and classify knowledge while also keeping in mind the potential 'harmfulness of overspecialization' can be traced back to the times of Greek philosophy at least (Klein, 1990; Moran, 2010). While the old 'disciplinas' served in the past above all the purpose of instruction and learning, the intent informing the modern system of disciplines extends beyond that (Stichweh, 2001): Disciplinary differentiation now serves as the primary structuring element of the social and communication system of science, teaching in secondary and higher education as well as the designation of professional careers and occupational roles beyond academia (ibid). Yet this disciplinary demarcation comes at a price. While disciplines provide orientation, structure and routines of practices, a common drawback is that disciplines can to a certain extent also become silos and "are often limited to reducing the problem to what they can capture

with their tools and terminology. They may [start] with a tunnel-view of the problem they are addressing" (Kaiser & Gluckman, 2023, p. 15).

The history of disciplines demonstrates that questions of differentiation and integration and, in particular, what constitutes an adequate balance between the two have always preoccupied humankind. Hence, ID and TD approaches are not necessarily new, however their explicit "political and discursive mobilization" (Lindvig & Hillersdal, 2019, p. 24) in academia certainly is. With the emergence of the term 'interdisciplinarity' in the first half of the 20th century (Klein, 1990) and 'transdisciplinarity' in the 1970s (Hirsch Hadorn, Biber-Klemm, et al., 2008; Jantsch, 1972; OECD, 1972, 2020; Piaget, 1972), the concept of integration gained new momentum. While specialization has contributed to technological developments and innovations, society also began to realize that there are "increasing social costs" attached to the "overspecializations of knowledge" (OECD, 1972, p. 10). ID and TD integration processes were further also perceived as an opportunity to take a self-reflective approach "on the inner workings of universities", and provided a "stimulus for further research and innovation" (ibid: p. 10), while also becoming increasingly identified as crucial research approaches to addressing contemporary grand challenges in the field of sustainability science (Kauffman & Arico, 2014; Lang et al., 2012; Mauser et al., 2013; Polk, 2015). In light of the literature presented, this thesis is based on the assumption that differentiation and specialization of knowledge is not problematic per se. However, it does become problematic when academia wants to address urgent complex and societally relevant problems, but employs deeply advanced, but singular and splintered perspectives on such problems in practice: If everyone focuses on specialization, who is able to embrace the bigger picture? (Schimank, 1996, p. 11). For instance, understanding and supporting sustainability transformations requires connecting ecological, social, economic, political, technological and cultural aspects and considering normative and power-related questions (Caniglia et al., 2021; Turnhout et al., 2020). Integration can therefore be seen as an answer and attempt to counteract the inability of the 'traditional' academic system to address complex problems by joining forces across multiple disciplinary boundaries as well as across the boundaries of science, policy and practice.

Today, the concept of integration is often hard to grasp although central to ID and TD research. Equating integration with 'consensus' has led to a certain skepticism towards this term among several scholars (Fam & Sofoulis, 2017; Grüne-Yanoff, 2016; Klenk & Meehan, 2015). However, other scholars have argued that 'integration' is still a central concept for conceiving, understanding and practicing ID and TD, emphasizing that 'consensus' is only one possible form of integration (Pohl et al., 2021). I argue that 'integration' is still a valuable concept for understanding and advancing ID and TD endeavors within discipline-oriented research contexts (Rocha et al., 2020) if not too narrowly defined and not exclusively focused on 'knowledge' integration (Boix Mansilla et al., 2016). This thesis is therefore based on the definition of integration by Pohl et al. (2021, p. 22), which define integration as an "open-ended learning process without pre-determined outcomes" between individuals participating in an ID or TD project. The goal of integration is then not necessarily to pursue a 'unity of knowledge' but to link

previously unrelated knowledge fields with each other in order to address a common purpose (Boix Mansilla, 2006), which cannot be addressed by single separated efforts (Newell, 2001). Integration along these lines should not be equated with a simple knowledge exchange or transfer (Godemann, 2008). It requires that individuals integrate this knowledge into their pre-existing knowledge structure, resulting in an adapted mental model (Godemann, 2008; Pearce et al., 2022; Pohl et al., 2021). Integrative outputs can take the form of, for instance, joint publications, synthesis reports, tools, policy briefs or any other formats useful for different target groups (Hoffmann, 2024). However, as Westberg and Polk (2016) noted, not all outcomes of TD processes can be put into words, yet TD processes are still considered worthwhile: they often contribute to the learning and personal development of the involved individual researchers and practitioners (e.g. a more comprehensive understanding of the issue at stake) and to the establishment of long-term cooperation among key actors (Polk, 2015; Schauppenlehner-Kloyber & Penker, 2015). The relevance of TD processes for partners from policy and practice was further reported to consist in "the capacity that is being built in their organizations and the possibilities of breaking silos within and between organizations" (Hansson & Polk, 2018, p. 139).While funding options for ID and TD endeavors have increased in more and more countries (Lindvig & Hillersdal, 2019), it still entails manifold challenges to pursue integration in practical terms (Djinlev et al., 2023; Hoffmann et al., 2017a). There are at least three dimensions of integration to distinguish between and respective challenges to be dealt with (Boix Mansilla et al., 2016; Pohl et al., 2021), namely a cognitive (e.g. bridging different logics, terminologies, methodologies), social-interactional (e.g. managing different working styles and expectations) and emotional dimension (e.g. creating a positive and respectful group atmosphere) (ibid). Project and program teams pursuing integration, necessarily have to proactively deal with these dimensions. However, how effectively they can do that, depends on the conditions under which they try to pursue integration. The role of conditions, leadership and methods for enabling integration will therefore be discussed in the subsequent chapter.

2.2. Enabling integration: conditions, leadership and methods

There has been extensive work on which factors influence ITD processes as well as on what kind of behaviors and actions team members ideally display in collaborative processes, as I will further outline below. When looking at those studies and theories in conjunction, one way of bringing them together, is to employ a structure-agency lens. The relationship between structure and agency is an ever-present topic in the realm of social sciences (Elder-Vass, 2010). The actions of individuals (i.e. actors) are always influenced – not determined – by the existence of structures. However, structures need to be reproduced to persist and can therefore also be altered through agency (Kempster & Parry, 2011). Society is therefore both, "the ever-present condition (material cause) and the continually reproduced (or transformed) outcome of human agency" (Hartwig, 2007, p. 469). Applying this to the context of ID and TD integration, I suggest that integration processes are influenced by pre-existing structures as well,

which tend to rather hinder or enable integration, while at the same time, different actors can transform these structures via their actions (Gugerell et al., 2023).

Structures can then be thought of as 'rules' which govern actions of researchers to a certain extent (Gugerell et al., 2023; Hartwig, 2007, p. 256). Various scholars have studied and approached these structures differently by developing different frameworks on enabling and hindering factors of ID and TD collaborations: Klein and Porter (1990) made a distinction between *external* (e.g. organizational context, available resources) and *internal* factors (e.g. employee characteristics, management style) to describe enabling or hindering conditions for ITD. Stokols et al. (2008, p. 111) suggested a six-factor-framework, distinguishing between (1) intrapersonal (e.g. an individual's willingness to devote time), (2) interpersonal (e.g. mutual respect between team members), (3) organizational (e.g. incentive structure in place), (4) technological (e.g. technical infrastructure readiness for collaborations), (5) physical environmental (e.g. distance/proximity to team members' working spaces), and (6) societal political factors (e.g. international collaborative policies in place). Wardani et al. (2022, pp. 381-382) synthesized practice-based literature according to a *micro-meso-macro* structure, namely the *individual* (e.g. experience and training in ID and TD skills), *relational* (e.g. communication and boundary spanning activities) and *structural* level (e.g. project organization, funding, disciplinary structure of academia, and socio-cultural and historical contexts). Salazar et al. (2012, p. 530) proposed an ecological perspective on integrative capacity in team science and distinguishes between (a) individual composition (e.g. collaboration experience), (b) team composition (e.g. knowledge diversity), (c) the organizational (e.g. institutional climate), (d) inter-organizational (e.g. clear collaborative arrangement) and (e) macro-context (e.g. government support for ID and TD).

In order to foster these necessary conditions, some scholars have then, for instance, focused on the development of individual capacities throughout academic studies and career development (Brundiers et al., 2010; Hoffmann, Deutsch, et al., 2022; Nurius & Kemp, 2019; Parker, 2010; Roy et al., 2020), while others have examined how to increase institutional capacity (Benson et al., 2016; Blythe & Cvitanovic, 2020; Bolger, 2021; Vienni-Baptista & Thompson Klein, 2022; Wernli & Ohlmeyer, 2023). This extensive literature represents an excellent knowledge base on enabling and hindering factors from different angles to subsequently build on, although it rather focuses on conditions for ID and TD research in general. There are few detailed empirical studies with an explicit focus on the conditions for ITD integration in particular. Notable exceptions are Bruce et al. (2004), Jakobsen et al. (2004) and Tress et al. (2007). In addition, it remains unclear how these different factors or levels are interlinked and inform each other in practice (Nurius & Kemp, 2019; Pennington, 2016).

The dialectical interplay between structure and agency (Fleetwood, 2005) gives rise to the question of which actors might have a potential role in mediating between the two, in particular in the context of ID and TD integration. A central task in daily ID and TD work is the mediation between the goals of an ITD program (e.g. working in a collaborative and interdependent manner), on the one hand, and the

structures that influence integration processes, on the other hand (e.g. incentivizing people to focus on disciplinary work for advancing their careers). This mediation is often assumed by the project or program leaders, who have a key role to play in integration processes (Bammer, 2008; Gaziulusoy et al., 2016; Gray, 2008). As Boone et al. (2020, p. 1731) note, "working within university power structures—to both challenge them and live within them—is a difficult part" of leading ITD processes. Leaders then have to "manage the tension between the need to innovate and the need to produce", and often "the familiar disciplinary research approach may appear as a faster path to productivity" (Mäkinen, 2018, p. 135; Uhl-Bien & Arena, 2018). The role of leadership is therefore important to integration processes – the more complex the ITD initiative, the greater the need for effective leadership (Hall et al., 2019, p. 596). Conceptual ambiguities exist between 'leadership' and 'management', two concepts which play a central role in the literature on ID and TD (Bammer, 2008; Defila et al., 2006; Hall et al., 2019). It can be observed in daily practice that leadership and management are sometimes used interchangeably, thereby blurring their differences. Despite a longer academic dispute in the field of leadership studies to what extent there is a difference between these two terms, Kotterman (2006) makes a strong case for treating the two terms as distinct concepts, although they might overlap in practice. While leadership entails setting a direction and promoting a vision, management involves developing and monitoring process steps and setting time lines to put the vision into practice (ibid). Also Hollaender et al. (2008, p. 392) supports a differentiation of project leadership and project management, each form "requiring different inputs and coordination efforts". Blackmore and Kandiko (2010, p. 55) suggest defining interdisciplinary leadership as the "leading of learning". Marion and Uhl-Bien (2001, p. 406) link leadership to "growth, fitness, innovation, and the future of organizations", while management means "tending to the nuts and bolts of detailed operations". They conclude that either leadership or management may be required, depending on the position or level in an organization. As advancing integration is often depicted as a management task, and often lacks dedicated resources (OECD, 2020), it makes sense to take a closer look at the role of leadership in integration processes and what this entails in terms of challenges, practices and tasks.

Central to agency and, in particular, to leadership are the tools and 'means' through which leadership can be exercised. If creating a common vision and direction is important for leading integration processes, the question arises as to how such a vision and direction can be developed. Hence, the question of means, especially integrative tools and methods for advancing integration, becomes important (Bergmann et al., 2012; Fischer et al., 2024; Hoffmann et al., 2017b). Loibl (2005, p. 10) suggests that 'braking energy' arising from inherent tensions in ID and TD teams can be converted into 'operating power' via suitable integrative methods. Different methods and toolboxes have therefore been developed to support researchers and leaders in addressing and incentivizing different parts, phases or challenges of ITD integration processes (e.g. establishing common ground, co-creating synthesis

products). Examples of method repositories are the td-net toolbox[2] by the Swiss Network for Transdisciplinary Research, the toolbox for philosophical dialogue[3] based at Michigan University, the Gaia toolkits of participatory research methods for sustainability[4], the WTT Toolbox[5] by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), the toolkit by the Centre for Unusual Collaborations (CUCo)[6], and the toolkit from 'Shaping Interdisciplinary Practices in Europe' (SHAPE-ID)[7]. While these tools are important for integration processes, it is also crucial to know how to use these methods and how to adapt them to concrete ID and TD project and program contexts, while also deriving experiences and lessons learned for future users. It is particularly useful to look at the application of these tools from a leadership perspective and to derive strategies for coping with emergent challenges to support the effective use of these tools in the future.

Before engaging with the outlined aspects (conditions, leadership, methods), chapter three delineates the research questions, the overall framework and the underlying philosophical assumptions of this study, followed by chapter four, wherein the qualitative research design is presented.

[2] https://naturalsciences.ch/co-producing-knowledge-explained/methods/td-net_toolbox
[3] https://tdi.msu.edu/
[4] https://gaia.oekom.de/index.php/gaia/participatory-research-methods-for-sustainability-toolkits
[5] https://www.wsl.ch/de/services-produkte/wtt-toolbox/
[6] https://www.unusualcollaborations.com/cuco-toolkit
[7] https://www.shapeidtoolkit.eu/

3. Research questions and philosophical assumptions

Current structures in academia and beyond often do not align with what would be needed to make ID and TD integration thrive (Hall et al., 2019; Jahn et al., 2012; Vienni Baptista & Rojas-Castro, 2020). While there is a lot of literature on enabling and hindering factors for ID and TD research in general, there are few empirical studies on conditions for integration in particular (see again 2.2.). What is more, the question arises how findings can be translated into concrete actions, hence be interpreted in the light of agency. In this thesis, I proposed to study the 'how-to' of integration by employing a structure-agency lens in line with a critical realist perspective (see further below). This has the advantage of providing a 'structuring' and 'systemic' element to the long list of enabling and hindering factors as outlined in chapter 2.2., while also identifying entry points of action by linking the agency potential of different actor groups with structures. Such an approach has the additional advantage of examining how different structural levels are interlinked and relate to each other (Gugerell et al., 2023; Nurius & Kemp, 2019; Pennington, 2016). The first research question (RQ) of this thesis is therefore:

> *RQ1: What are enabling conditions for inter- and transdisciplinary integration at different structural levels and how do they interact with each other?*

Different scholars have attributed the agency potential and leverage power essential for integration to one particular actor group, namely leaders of ID and TD integration processes (Gray, 2008; Hollaender et al., 2008; Mäkinen, 2018). While the general challenges attached to integration are well documented in the literature (Lang et al., 2012; Lawrence et al., 2022), the challenges that leaders of integration processes face in particular and the strategies that prove useful for addressing them remain unexplored. In other words, although integration is considered critical to the success (or failure) of ITD programs and networks, only a few empirical studies examine how these integration processes can be effectively led (Eigenbrode et al., 2017; Hoffmann, Weber, et al., 2022; Mäkinen, 2018; Palmer, 2018). The second research question of this thesis therefore asks:

> *RQ2: What leadership challenges do leaders of inter- and transdisciplinary research programs need to deal with during integration processes and what strategies and integrative methods haven proven fruitful to address them?*

Although framed as 'what'-questions, both RQ1 and RQ2 are inherently linked to the 'how-to' of integration since they examine conditions, leadership practices and methods, which can enable integration. The third research question is cross-cutting to the two previous ones and aims to generate action-oriented knowledge (Bruce et al., 2004; Fazey et al., 2018) for strengthening ID and TD integration in practice:

> *RQ3: Based on the insights yielded from the first two research questions, what practical implications can be derived for different actor groups to create more favorable conditions and address current challenges related to integration?*

By means of these three questions, my thesis aims to study how different conditions as well as leadership manifest in concrete terms in day-to-day integrative ITD work, while also elucidating how difficult conditions and leadership challenges can potentially be dealt with. Given that larger ITD programs have become more and more common in academia to address current sustainability challenges (Black et al., 2023; Defila et al., 2015; Kloet et al., 2012; Weith et al., 2019) and that such larger-scale initiatives are likely to face even higher barriers to integration due to their complexity (Tress et al., 2007), I decided to study these questions in the context of three large ITD research initiatives in Switzerland (see 4.1.). Figure 1 presents the overall framework of this thesis and situates the contributions of each article. Table 1 provides an overview of the three research articles, which research questions were addressed in each, their current status and respective key insights. The overall intention of my thesis is not to suggest a one-size-fits-all structural or leadership model for ITD contexts, but to identify underlying structures and mechanisms with the potential to generate certain 'tendencies' (Sayer, 2000, p. 127). The understanding of these tendencies can help leaders and their team members as well as funders and research institutions, to both anticipate and diagnose the acute challenges ITD initiatives face, hence empowering these participants to act on them more proactively. Or in other words, by distinguishing between and spanning across different structural levels in the analysis, a more systemic and solid understanding of the conditions and leadership aspects integral to integration in such contexts can emerge, which then can also form the basis for improving them (Wren & Swatez, 1995).

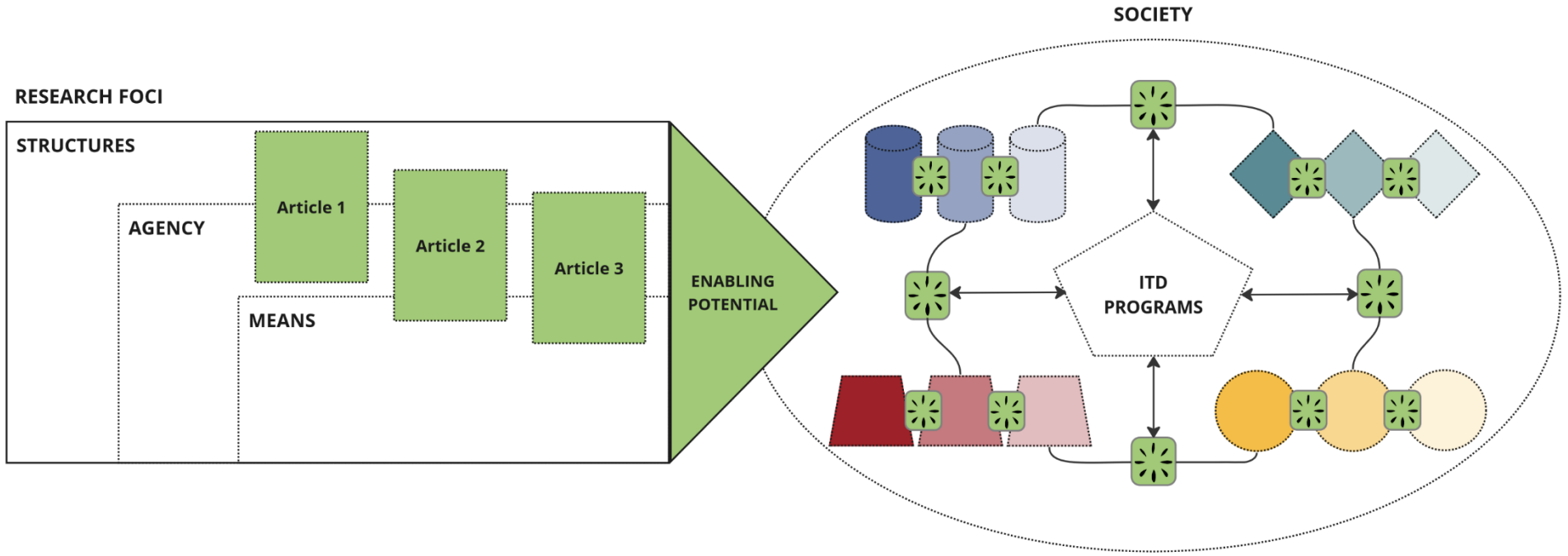

Figure 1: Overall framework of the thesis (own elaboration). ***Right side:*** *Complex and differentiated societies (Luhmann, 1977) are composed of multiple sectors, institutions, disciplines and actor groups (represented by the different shapes). This poses the risk of working in a silo- structure. However, this potential for silos exists to a certain extent also within sectors (e.g. different departments within an institution that are not used to working together, represented by the different color shades). Each sector, institution, discipline or actor group tends to work efficiently within their own field or sphere of responsibility. Challenges arise when trying to work at the interfaces and pursuing integration across departments, institutions, actor groups or entire sectors. Working at the interfaces (symbolized by the spark symbol) affords opportunities to address complex questions in an integrated and innovative manner, but also invites potential for conflicts and tensions. ITD programs create a space for addressing the potential tensions and harnessing the potential for innovation at the interfaces in a productive manner.* ***Left side:*** *This thesis looks at the 'how-to' of integration by embracing three research foci (structures, agency, means) for enabling integration in the context of ITD research programs. The figure displays the scope of each research article and to what extent they address structures, agency and means. It further depicts the overall goal of the thesis: supporting the enabling of ID and TD integration in practice*

Table 1: Overview of the three research articles, their current status, foci and key insights

Article	Title	Authors	Journal	Status	RQs	Focus and key insights
1	Creating favorable conditions for inter- and transdisciplinary integration – an analytical framework and empirical insights	- Lisa Deutsch - Christian Pohl - David N. Bresch - Sabine Hoffmann	Global Environmental Change	Under review: 1st decision: revise & resubmit	1, 3	- Presentation of an analytical framework which outlines conditions for enabling integration in practice at different structural levels - Practical recommendations for individual team members, leaders, funders, directorates and science policy-makers for creating more favorable conditions for ITD integration - It is necessary to remove unnecessary stumbling blocks for ITD integration to ensure that ITD teams can focus on the 'natural' challenges of integration
2	Herding cats - Integrative leadership strategies in inter- and transdisciplinary research programs	- Lisa Deutsch - Astrid Björnsen - Andreas M. Fischer - A. Michiko Hama - Niklaus E. Zimmermann - Christian Zurbrügg - Sabine Hoffmann	Sustainability Science	Under review: revised and resubmitted	2, 3	- Presentation of six core leadership challenges that leaders of large ITD programs in Switzerland faced during integration processes - Practical insights and strategies for dealing with those challenges to support fellow and future ITD program leaders as well as recommendations on explicit leadership resources in the future - Integrative Leadership entails mobilizing supportive and creative contributions from both leaders and program members, and requires different types of expertise, experience and skill-sets, depending on the program phase and task
3	Leading inter- and transdisciplinary research: Lessons from applying theories of change to a strategic research program	- Lisa Deutsch - Brian Belcher - Rachel Claus - Sabine Hoffmann	Environmental Science & Policy	Published	1, 2, 3	- Description of the application of the integrative method 'Theory of Change (ToC)' within the ITD program Wings at Eawag in Switzerland - Reporting and reflection upon the leadership challenges during the application processes and derivation of lessons learned for future uses - The ToC process can be useful for facilitating integration across projects, disciplines and actors within large ITD research programs. Several challenges persist given tensions arising from the incentive structure in academia

Critical realism (CR) provides the meta-theoretical framework and philosophy of science for identifying such structures on different levels as well as the related generative mechanisms (Sayer, 2000) impacting integration processes, integrative leadership and the employment of integrative methods. It is important to make explicit which philosophical assumptions underlie our research practice since it determines which assumptions we make about reality and our ability to approach and understand it (Creswell & Poth, 2018). In addition, it strongly informs the choices we make and actions we take as researchers during the entire research process (ibid). CR starts from the assumption that there exists a world independent of our knowledge of it (Sayer 2000). Roy Bhaskar (2008, p. 11) introduced a distinction between 'intransitive' and 'transitive' dimensions of science. While the objects of science such as natural or social phenomena constitute the 'intransitive dimension' of science, the discourses, interpretation and theories about them represent the 'transitive dimension'. While different and sometimes conflicting theories of different researchers can exist (i.e. different transitive objects), the intransitive dimension (i.e. the world under study) is the same (Bhaskar, 2008; Sayer, 2000, p. 11). Based on this distinction, critical realism assumes a stratified ontology by distinguishing further between 'the real', 'the actual', and 'the empirical' (ibid):

- '*The real'* constitutes "whatever exists, be it natural or social, regardless of whether it is an empirical object for us, and whether we happen to have an adequate understanding of its nature" (Sayer, 2000, p. 11). Those objects under study are characterized by specific structures and powers, which exist independently from our knowledge of it (Bhaskar, 2008).
- *'The actual'* constitutes the realm of what happens when those powers are exercised, hence the realization of what is possible due to the structures of 'the real'. Powers may remain unexercised, which does not mean that they lack the potentiality to be exercised (Hartwig, 2007; Sayer, 2000).
- *'The empirical'* is defined as the "domain of experience", and comprises the observation of the realization ('the actual') of the powers and structures ('the real') (Collier, 1994). However, the mere fact that we cannot observe certain things does not permit us to conclude that they do not exist. As Sayer notes: "Observability may make us more confident about what we think exists, but existence itself is not dependent on it." (2000, p. 12).

Sayer provides an illustrative example of this distinction by referring to the distinction between labor power and labor. While the labor power of humans is the mental and physical capacity to work and belongs to the domain of 'the real', labor itself is the realization of that capacity and belongs to the 'the actual'; when we can, in turn, observe the realization of labor power, for instance because we see people working, we find ourselves in the domain of 'the empirical' (ibid). This stratified ontology has important consequences for the reasoning and inference modes employed in research practice. It makes apparent that the traditional logical modes of inference, deduction and induction are important, but not always sufficient for identifying the structures and powers located in the domain of 'the real' (Danermark et al.,

2002): While the limitations of deduction are that nothing new can be derived, which is not already part of the premises, limitations to induction entail that the observation of empirical regularities doesn't necessarily tell us anything about the underlying structures and mechanisms generating them in the first place (ibid). In order to study the latter, it is necessary to engage in transcendental reasoning, hence abduction and retroduction become key (Willis, 2019). Abduction means to recontextualize an observed phenomenon, hence to reason about observations in the light of different theoretical frameworks so as to link it to more general concepts (Danermark et al., 2002). Retroduction aims "to arrive at what is basically characteristic and constitutive of the structures" under study (ibid: p. 96). This means that by abstraction and careful conceptualization, one aims to identify the components and influential categories of a phenomenon as well as their interrelationships. One infers from effects (i.e. the 'actual', and if observed the 'empirical') to more overarching explanatory structures (i.e. the 'real') (Hartwig, 2007, p. 257). Retroduction is therefore guided by transcendental questions such as 'What makes X possible?', 'What properties must exist for X to be what X is?' or 'What causal mechanisms are related to X?' in order to approach non-observable and less tangible aspects of a phenomenon (Danermark et al., 2002, p. 97). Since the intention of this thesis was to derive different structures and their inherent powers, which influence to what extent integration can be realized, I also needed to engage in abductive and retroductive reasoning by asking transcendental questions during data collection (Willis, 2019) and when analyzing the empirical material and synthesized literature on ITD integration (see chapter 4.2.).

4. Research design

This thesis builds upon a qualitative accompanying research design (i.e. *Begleitforschung*) (Defila & Di Giulio, 2018b), being composed of three case studies. A case study is suitable when a research project examines "a contemporary phenomenon (the "case") in depth and within its real-world context" (Yin, 2014, p. 16). My research design was *exploratory* as it explored how integration in general and integrative leadership in particular is practiced across different cases; however, it also sought to be *explanatory* as I examined how and why certain conditions and leadership practices enable integration (or not) via abductive and retroductive reasoning (see chapter three). In the following, I first outline the accompanying research design and the three cases I studied in depth, followed by a description of the qualitative methods used to collect data and the analysis procedure I employed before providing a final reflection on my role and positionality during the research process.

4.1. Accompanying research and case studies

I conducted accompanying research in three different ITD initiatives in Switzerland from October 2020 to December 2023. I chose Switzerland as a case study context for several reasons. First, its rich history and tradition of applying ID and TD approaches (Hirsch Hadorn, Hoffmann-Riem, et al., 2008; Paulsen & Kueffer, 2023) provided an excellent pool of experiences and a dynamic field of many on-going ITD initiatives from which to choose. Second, I had already been involved in the Swiss ITD program 'Wings' at Eawag since April 2019, which provided an opportunity to turn that program into an in-depth case study due to the trust and collaboration that had already been established. Third, due to my qualitative in-depth design it made sense to choose two geographically close ITD research initiatives in order to allow for regular face-to-face interactions with its leaders and team members. Forth, since it was intended that the project also facilitates cross-institutional learning within the ETH domain (i.e. in total 6 Swiss federal research institutions) in terms of the aforementioned research questions, it became important to choose Swiss (research) institutions as additional cases.

The three ITD initiatives studied were therefore (1) the research program 'Extremes' at WSL (Swiss Federal Institute for Forest, Snow and Landscape Research), (2) the cross-sectoral network NCCS (National Centre for Climate Services consisting of seven Swiss Federal Offices, WSL and ETH Zurich) and its ITD research program NCCS-Impacts, and (3) the research program 'Wings' (Water and sanitation innovations for non-grid solutions) at Eawag (Swiss Federal Institute of Aquatic Science and Technology) (see Figure 2 and Table 2). All three ITD initiatives had the ambition to address a complex urgent societal problem (i.e. future extremes, climate impacts, sustainable urban water management) by integrating perspectives from different disciplines (spanning from social to natural and engineering sciences) as well as from policy, industry and practice, ultimately aiming to come up with relevant synthesis outputs for the program partners and other overarching target groups.

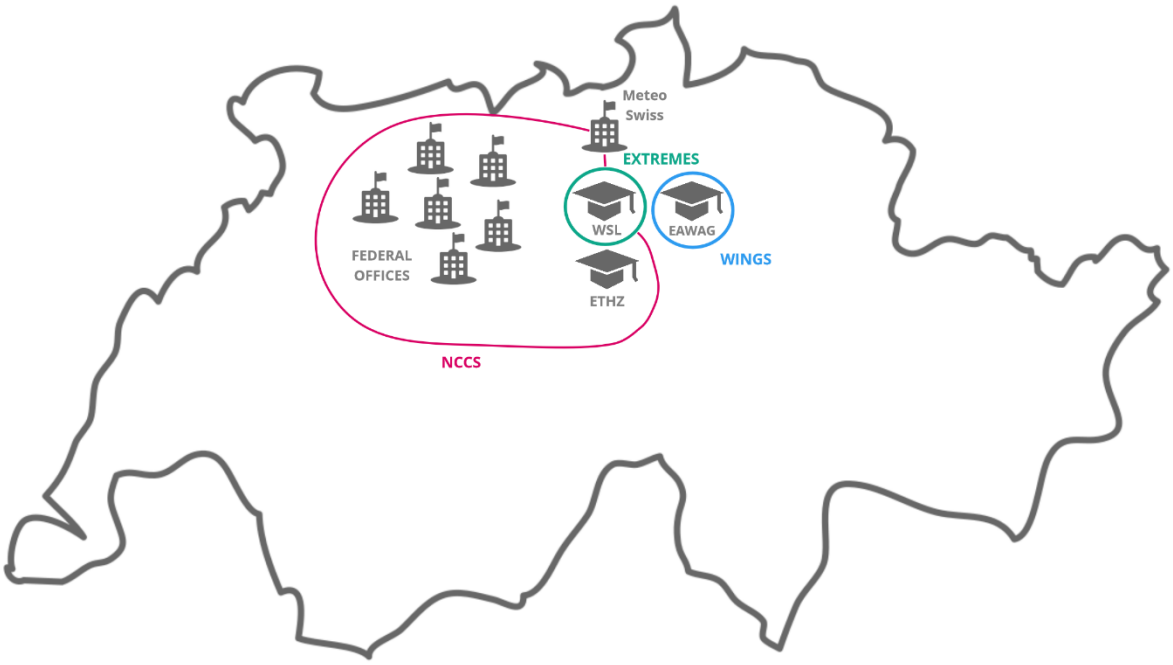

Figure 2: Overview and location of the three case studies Extremes, NCCS and Wings (own elaboration). The lines represent the core team boundaries at the program level of each case study (network level in the case of the NCCS). The core team is important as it meets on a regular basis and is strongly involved in decisions on the program's overall course. The composition of both the Extremes and Wings core team was interdisciplinary i.e. researchers from different WSL and Eawag internal disciplinary departments. The core team of the NCCS network is transdisciplinary and consists of representatives from two research institutions (ETH Zurich and WSL) and seven federal offices). The diverse partners from policy, industry and practice on the project level of each case study are not depicted in the figure, but displayed in Table 2. While Extremes and NCCS are related content-wise, they do not overlap in terms of program/network structure, but are two independent initiatives. However, while Extremes is a WSL internal program, WSL as institution also forms part of the network NCCS.

As Fiedeler et al. (2010) note, the German term '*Begleitforschung*' does not have an exact English equivalent, but is usually translated as 'accompanying research'. This term carries multiple meanings and is strongly used in the field of technology development, which encompasses analysis of the potential impacts of the former on multiple levels (ibid). However, the type of 'Begleitforschung' I conducted, entailed studying integration processes in different ITD research programs by *accompanying* them in their daily research practice from a social-scientific perspective. As the verb 'accompanying' entails, it meant that I was present among the integration processes of these programs with varying degrees of proximity and in different roles over time (see chapter 4.3. on positionality). This meant conducting research on how others practice ID and TD integration and thereby examining the 'inner workings' of a collaborative process (Freeth & Vilsmaier, 2019). This type of accompanying research often involves elements of ethnographic studies, employing participant observation and related methods to study group processes (Thompson, 2009).

Typically, research programs are 'funding lines', i.e. often thematic calls for projects by funding institutions such as the National Research Programs (NRP) by the Swiss National Science Foundation (SNSF) (Defila & Di Giulio, 2018b). The selected projects start more or less at the same time and are carried out individually, but share an overarching, often societally relevant topic. However, they are not necessarily "designed and chosen to collaboratively produce integrated results" (ibid: p. 98.). The three

case studies of this thesis share some similarities with this definition of research programs, but also differ in a number of respects. All three ITD research programs were comprised of several individual projects, which worked on a common topic (e.g. future extremes). These projects started more or less at the same time in the case of Extremes and NCCS-Impacts. In Wings, some projects started at the same time, but they had different durations (i.e. ended earlier/later and therefore produced results and outputs earlier/later), while also new projects were kicked-off repeatedly during the course of the program. The latter was also a key ambition of Wings, namely to remain responsive to emergent research needs, and to launch or include new projects based on new research gaps or potential for synergies identified along the integration process. Additional differences include that all three ITD research programs intended from the very beginning to produce integrated results across the individual projects and to hence arrive at synthesis products and new knowledge on the program level. None of the three research programs was funded by a single external funding line or source. Extremes was funded as a strategic priority by the WSL directorate. Wings was composed of projects financed by several different funding institutions (see Table 2), including discretionary funding at Eawag. The case of the NCCS-Impacts is particularly interesting, as different Swiss federal offices have pooled substantial funding for the first time in order to finance a joint and integrated research program for dealing with cross-sectoral climate impacts in Switzerland. Inherent to and interesting about all three research programs is the strong bottom-up component. Wings, NCCS and its program NCCS-Impacts emerged entirely bottom-up through the initiative of a small circle of its later founding members (Wings: Eawag researchers; NCCS: representatives of Swiss federal offices; WSL; ETH Zurich). 'Extremes' was to a certain extent initiated by the WSL directorate, but further structure and content were created bottom-up via a series of co-creation workshops prior to publication of the call (Björnsen & Zimmermann, 2022). All research programs (Extremes, NCCS-Impacts, Wings) and the network NCCS had either a main and deputy-, or a co-lead. In addition, Extremes, Wings and the NCCS also hired a third person (i.e. communication expert, scientific assistant, PhD student) either from the very beginning or throughout the duration of the program/network to support its leadership.

Table 2: Overview of the three ITD research programs (case studies) in Switzerland

ITD program	Extremes	NCCS/ NCCS-Impacts	Wings
Topic	Future extremes	Cross-sectoral climate impacts	Sustainable urban water management
Based at	Swiss Federal Institute for Forest, Snow and Landscape Research (WSL)	Swiss Federal Office of Meteorology and Climatology MeteoSwiss (Executive Directorate), together with six other Swiss Federal Offices of Public Health, Civil Protection, for the Environment, for Agriculture, for Safety and Veterinary Affairs, for Energy and two research institutions: ETH Zurich & WSL	Swiss Federal Institute of Aquatic Science and Technology (Eawag)
No. of projects	5	7	10-14
No. of collaborators	~ 20-25 (core team) ~ 90-100 (core team plus partners from science, policy and practice)	~ 20-25 (core team) ~100 (core team plus partners from science, policy and practice)	~6 (synthesis team) ~20-25 (core team) ~80 (core team plus partners from science, policy and practice)
Leadership & assigned work percentage (full-time equivalent)	Two co-leaders (30% each); One scientific assistant since 2023 (40%)	NCCS: Two leaders (director: 80-100% & deputy director: 80%); One science communication expert since 2022 (80-100%) NCCS-Impacts: NCCS deputy director (80%) and communication expert (80-100%) serve as program leader and deputy program leader	Two leaders (main lead: 50% & deputy lead: 10%); One scientific assistant/PhD student since 2016 (50-80%)
Disciplinary background of program participants	Biodiversity, Cryospheric Sciences, Ecology, Forestry, Hydrology and Environmental Psychology	Medicine, Veterinary Medicine, Ecology, Agronomy, Economy, Sociology, Forestry, Hydrology, Energy, Climatology, Geography	Environmental Engineering, Environmental Health Psychology, Decision Analysis, Human Geography, Innovation and Transition Studies, Inter- and Transdisciplinary Studies, Political Science, Process Engineering, Urban Planning
Partners involved within the individual projects	Representatives from Swiss cantons and federal offices, research institutions, regional electricity provider, and associations	In total, 17 partners undertake the work in the form of consortia. The consortia are composed of representatives from organizations from research and practice: research institutions, consulting agencies, foundations, communication agencies and NGOs	Representatives from Swiss cantons and municipalities, Swiss federal offices, utilities, sewage treatment plant operators, spin-offs, water associations, planning offices and consulting agencies
Funding	WSL internal funding	Joint funding by involved Swiss Federal Agencies	Eawag internal funding, Swiss National Science Foundation, Bill & Melinda Gates Foundation, Swiss Federal Office of Environment, Swiss Agency for Development and Cooperation, in-kind contributions of involved researchers
Duration	2021-2025	The NCCS-Impacts program runs from 2022-2026; the NCCS itself is a permanent network of the Swiss Confederation operating since 2015	2016-2018 (Phase I); 2019-2022 (Phase II)

My accompanying research design is based on the typology developed by Defila and Di Giulio (2018b), who suggest analyzing and distinguishing between different types of accompanying research on ITD programs along three dimensions: (a) the kind of research, (b) the relationship to the actors, and (c) the process-related tasks performed. Based on this, they suggest a typology of three types: (1) the complementary type, (2) the meta-type and (3) the integration-oriented type (see Table 3).

Table 3: Three types of accompanying research to research programs adapted from Defila and Di Giulio (2018b)

	Type 1: Complementary Type	**Type 2: Meta Type**	**Type 3: Integration-oriented Type**
Research: *What kind of scientific knowledge is produced?*	K1 – knowledge about the topic of the research program	K2 – knowledge about processes taking place in the research program	K3 – integrated knowledge either about the topic of the research program or about processes taking place in the program
Relationship to the actors: *What is the special relationship to the other projects?*	R1 – no special interaction R2 – use of data/results of the projects	R3 – projects are object of research	R4 – setting the stage for the projects' collaboration R5 – collaboration with the projects
Process-related tasks: *What additional tasks can be incorporated?*	No additional tasks	Supporting dissemination (coaching/consulting)	Supporting dissemination (coaching/consulting)
Case Studies	None of them	Extremes, NCCS, Wings	Wings

As Defila and Di Giulio (2018b) outline in their typology, accompanying research can pursue different objectives and therefore also produce different kinds of scientific knowledge. The type of accompanying research I performed differed according to the case study. Overall, in all three programs, the aim of my accompanying research was to produce knowledge about program-internal processes (type 2: meta-type research). This meant I assumed a role as an investigator, instead of generating knowledge on the program's topic or advancing integration across the projects of the respective program involved (Defila & Di Giulio, 2018b; Weith et al., 2019). However, within Wings my role was much more differentiated, varied over time and relative to the 'hat' I intentionally put on in different situations. Before starting my PhD studies in October 2020, I had already been a scientific assistant within Wings for 1.5 years, supporting the leadership (i.e. the program leader Sabine Hoffmann) in co-leading integration within the program with an 80% FTE (full-time equivalent) working percentage. I continued my involvement in this role when starting my PhD in order to further experience the challenges of co-leading integration processes myself, but reduced it to 40-50% per week. Hence, within Wings I did not only assume the investigator role, but also assumed an integrator role, hence conducted the integration-oriented type of accompanying research (type 3). In neither of the case studies did I assume a complementary type of accompanying research (type 1) since the goal of my study was not to create complementary knowledge on the program's topic (i.e. future extremes, climate impacts, sustainable urban water management), but to examine inter- and transdisciplinary integration processes from a meta perspective (type 2) and to advance those processes within Wings myself (type 3). This arrangement of conducting two different types of accompanying research posed both opportunities and

challenges, while also creating interesting questions in terms of positionality, which I will further discuss in chapter 4.3.

4.2. Methods and analysis

In order to deal with the complexity of conditions and leadership influencing integration processes in ITD contexts, it is key to draw from a variety of evidence. To study the three research questions in depth, I triangulated four different qualitative methods: semi-structured interviews, participant observation, focus groups and reflexive journals. In addition, a significant amount of experiential evidence as well as more unstructured, but scheduled exchanges over coffee or lunch with the program leaders, and an uncountable number of spontaneous hallway- and by-the-printer conversations in the case of Wings at Eawag, complemented the emerging picture. An overview of how these methods were employed and the number of encounters is given in Table 4[8].

The semi-structured interview guideline (see appendix) was developed in line with retroductive reasoning (see chapter 3 on philosophical assumptions) by building upon the work of Willis (2019) in order to look for underlying conditions for integration and leadership at different levels. To conduct participant observation, I embraced two strategies: at the beginning of my study, I joined meetings and retreats without consciously looking for specific themes or aspects, but rather intended to learn as much and as openly as possible about the program Extremes and the network NCCS, which were completely new to me. Over time, I specifically looked for what challenges people reported during the meetings with regards to integration, what reasons were stated for this and what strategies were suggested or discussed to address them. I further observed how integration was enacted by the program leaders (e.g. the methods they used, how they structured the activity as such, and how they tried to motivate and bring everyone on board). The focus group topics I chose were in line with the themes that emerged from the interviews with both program leaders and members over time. They usually represented overarching themes common to all case studies and were related to the three research questions. To structure those focus groups, I used and tested different creative and visual methods such as reversal techniques (Lungershausen, 2017) and the soft-systems methodology (Pohl, 2020). Initially, it was intended that all program leaders use a reflective leadership tool on a regular basis (Deutsch & Hoffmann, 2021b). However, due to time constraints, this method did not prove feasible in all three contexts. Nevertheless, it was once used for a debriefing after a retreat in the context of the NCCS and at several, but not regular, instances within the Wings program. Reserving explicit time for individual

[8] My study was approved by the ETH ethics commission (EK 2022-N-15) and all interviewees were informed in written form of the study, its scope and the procedure of data collection, analysis and storage. All of them gave their written consent to participating in the study, and were given the opportunity to read and comment on the manuscripts before I submitted them to the journals.

reflection, proved to be very challenging and was easier and also more appreciated by participants when done jointly and in a formal setting (i.e. during bi-annual focus groups with the program leaders).

Table 4: Overview of the methods employed and collected data

Method	Rationale	Data
Semi-structured interviews (Knott et al., 2022)	Used for exploring the interviewee's (a) definition of integration, (b) their experienced good-practice and bad-practice examples of integration, (c) the conditions under which those examples took place, and (d) how they conceptualized, experienced and practiced leadership in their respective programs	• 20 interviews with program/network members (8x Wings, 7x NCCS, 5x Extremes) • 8 interviews with program leaders (two leaders were interviewed twice, to get to know the case studies) • 6 open exchanges with program leaders over coffee or lunch • Duration: 1.5-2hrs • Location: Cafés, personal offices of interviewees or via Zoom
Focus groups (Creswell & Poth, 2018)	Used for (a) exploring emerging themes from the interviews (e.g. how to ensure accountability and responsibility on the program level) and from further participant observation in a group setting i.e. the group of the six program leaders; (b) discussing daily integration challenges and what strategies they employ to deal with them in depth; (c) incentivizing peer-to-peer exchange among the six program leaders	• 5 focus group meetings with program leaders (every 6 months) • Duration: 3hrs each followed by joint lunch • Location: Online (Kick-Off during Covid19 Lockdown), then shifting across involved institutions i.e. 2x at Eawag, 1x at WSL, 1x at MeteoSwiss
Participant observations (Creswell & Poth, 2018)	Used for (a) understanding the specific program context and getting to know the program members better; (b) observing integration challenges and applied strategies 'in action'; (c) complementing insights gained from interviews and focus groups, hence going beyond what was articulated by the interviewees	• Extremes: 5 meetings • NCCS: 5 meetings • Wings: > 50 meetings • Half-day or full-day followed by after-work receptions ('Apéros') • Location: respective institution or at ETH Zurich
Reflexive journals (Hyers, 2018)	Used (a) ex-post for documenting ITD meeting dynamics, (b) reflecting upon what has caused this dynamic and what this might mean for future meetings in general and leadership practices in particular; (c) diving deeper into concrete incidents of (non)-integration and (d) exploring underlying mechanisms right after they had surfaced during a meeting	• Selectively used within Wings • Once used for debriefing workshop within NCCS • Location: used individually and once via Zoom • Used reflection tool: Deutsch and Hoffmann (2021b)
Experiential evidence	Gathered by being strongly involved in the leadership of the program activities, in particular organizing, implementing, co-leading and debriefing program meetings, workshops and retreats, as well as organizing continuous follow-up activities (e.g. Theory of Change) and developing joint synthesis outputs (e.g. synthesis video, policy briefs, etc.).	• 30 program meetings (each 2 hrs.) and protocols (organization, implementation and documentation) • 6x 1.5 days program retreats • 14 interdisciplinary workshops (each 2 hrs.) • Indefinable number of bilateral formal meetings (24 times for the development of ToC alone) • Development of synthesis products

The empirical data was recorded, transcribed and analyzed via qualitative content analysis, more specifically – in line with a critical realist approach to grounded theory (Oliver, 2012; Strauss & Corbin, 1990). This meant that I iteratively employed inductive coding to allow for new categories to emerge, and deductive coding based on my interview guideline and the literature on ITD integration and

leadership. I further engaged in abductive reasoning (Timmermans & Tavory, 2012), which means interpreting empirical findings in the light of different or new conceptual frameworks. In concrete terms this meant, for instance, analyzing my findings in the light of concepts from psychology and organizational studies. I also employed retroductive reasoning, which means to constantly ask in parallel about the larger structural issues behind the empirics (Oliver, 2012). This implied going beyond what was explicitly stated by the interviewees and placing the different identified conceptual categories from the previous steps in relation to each other (ibid). How I analyzed the data with respect to each research question and in the context of the specific research article is described in the chapters five, six and seven.

4.3. Positionality and role reflection

Every research process "is "positioned" and "within a stance" (Creswell & Poth, 2018, p. 228), which makes it imperative for researchers to be explicit about (1) the motivation to conduct the study, and (2) the researchers' role in relation to others (Creswell & Poth, 2018; Darwin Holmes, 2020):

With regards to *(1) my personal motivation*, it is important to note that prior to my employment at Eawag, I had gained initial experience in doing ID and TD research during my interdisciplinary Master program 'Socio-ecological economics and policy" at the Vienna University of Economics and Business (WU Vienna), and within an ITD project on nature-based solutions at *Technische Universität (TU) Darmstadt* in Germany and its case studies in Costa Rica and Nicaragua. During these all together three years, I collaborated across disciplines, as well as with representatives from policy and practice myself and therefore was already well aware of the integration challenges when joining Eawag in April 2019 as a scientific assistant of the Wings program. Wings then provided me with yet another set of experiential knowledge complementing the previous experiences of doing ITD research. By the time I started my PhD in October 2020, I had gained experience with ITD research on different scales (at graduate studies, project, and program level), in different countries (Austria, Costa Rica, Germany, Nicaragua, Switzerland), different institutional settings (WU Vienna, TU Darmstadt, Eawag) and had collaborated with a wide variety of team members spanning different hierarchies (Austria: master students from different disciplines, Germany: PhD students from different disciplines as well as practice partners in Nicaragua and Costa Rica; Switzerland: senior and junior researchers, and practice partners). Despite the differing contexts, I had gained the impression that there were structural and often unexpressed factors influencing ITD integration processes common to all cases. I further assumed that leadership might be an important leverage for enabling integration in practice and became interested in how leadership can be enacted in such contexts for dealing with the manifold challenges attached to integration. Having experienced both the potential and challenges of ITD research, my motivation for conducting this PhD research was to explore enabling conditions for ITD integration in order to better allow the integrative potential of ITD projects and programs to unfold in the future.

My *(2) research role* within the three different case studies was strongly influenced by my accompanying research design. As Fiedeler et al. (2010, p. 1) note, accompanying research has an inherent 'relational notion' since it expresses that one research activity is carried out in parallel to another. The relationship between myself and the three cases was characterized by dependency (I relied on participants sharing their thoughts and experiences openly) and unequal distribution of power (I acquired in-depth knowledge about the program's internal and sensitive affairs, but not necessarily vice versa) (Defila & Di Giulio, 2018b, p. 100). Ensuring confidentiality and anonymity were therefore key. I also decided not to take a mere 'distant observer' stance, but to be always open and remain available to answer any questions participants might have not only about the study itself but concerning my personal experiences or lessons learned with regards to ITD research as well. When I was approached with a specific problem or challenge by a participant, I was open to sharing anonymized anecdotes and personal learning from previous contexts. I always answered genuinely, never holding back information intentionally for the purpose of 'not influencing' the research setting.

During my accompanying research, I assumed different degrees of insider and outsider roles, both having advantages and limitations. Performing a double role of conducting both a meta-type as well as integrator-type of research within Wings meant remaining involved in the leadership of the program, while studying it at the same time. This provided me with hands-on experience and detailed insights by having access to the 'black box' of internal processes (Weith et al., 2019, p. 297; Zscheischler et al., 2017; Zscheischler et al., 2018). Program participants had known me already for some time and trust had been established. At the same time, being close to the team and being responsible for integration together with the program lead meant that I was emotionally more invested and affected when meetings ended unsatisfactorily. It was also challenging to switch from an insider (doing integration) to an outsider role (observing integration), sometimes even within the same meeting. However, in turn, jumping back into the 'observer' and 'curious learner role' allowed me to gain emotional distance and to experience certain situations not so much as frustrating but as suddenly highly interesting. The situation was different in the case of Extremes and NCCS, since I neither knew the leaders nor the participants beforehand. I therefore started as a mere outsider, which allowed me to approach these two ITD initiatives with more distance. Yet, being a complete outsider relative to the case studied also has disadvantages, as Freeth and Vilsmaier (2019, p. 58) noted in remarking that the newcomer is "lacking a deep understanding of the challenges and difficulties that are faced inside collaborative teams". Instead of viewing it as a dichotomy, I agree with Darwin Holmes (2020, p. 6) in viewing the insider-outsider roles as a continuum. This was to a certain extent also the case within the other two case studies (i.e. Extremes and NCCS) as over time a certain familiarity emerged. For instance, further on I was included in group pictures at the end of program meetings, as I was told to have "also 'shaped' the course of the program" (program leader). My research positionality can therefore be described as having been 'in movement' (Freeth & Vilsmaier, 2019, p. 59) over time and across case studies. The subsequent

chapters five, six and seven will illustrate my accompanying research design in more detail and present its empirical findings.

5. Creating favorable conditions for inter- and transdisciplinary integration – an analytical framework and empirical insights (article 1)

Status and journal: Under review in *Global Environmental Change*; first decision: revise and resubmit

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Keywords: Interdisciplinary, Transdisciplinary, Integration, Environmental Change, Sustainability, Science to Action

Abstract: Complex phenomena of our time such as climate change or more recently, the Covid-19 pandemic can neither be comprehensively understood nor properly addressed by employing a single disciplinary or sectoral perspective. For this reason, more and more inter- and transdisciplinary (ITD) initiatives are on the rise, intending to open up the silo-like production of knowledge, and to advance the integration of different fields of expertise within academia but also across science, policy and practice. While the need for ITD endeavors also has increasingly been acknowledged by research institutions, funders and public authorities, the question remains to what extent these conditions suffice for making ITD integration really happen in practice. This paper embraces a holistic view on ITD integration by presenting both an analytical framework and empirical data from three ITD initiatives based in Switzerland dealing with sustainable water management, (future) extreme events and climate services. The framework is based in critical realist reasoning and empirics, and distinguishes contextual conditions of integration at different structural levels, while also acknowledging the power of actors to shape integration. The paper thereby illustrates and helps diagnosing where different fields of tension come from, and how they are interrelated and impact ITD integration. We conclude by discussing entry points for action for several actors interested in making sure that ITD initiatives with the ambition to address the sustainability challenges of our time can unfold their full integration potential in practice.

5.1. Introduction

Despite the promising potential of inter- and transdisciplinary (ITD) integration for addressing urgent wicked problems such as sustainability challenges arising from global environmental change (Palmer, 2018; Steger et al., 2021), it is inherently complex to make integration happen in practice. Given the complexity of ITD integration, it could be regarded a wicked problem in itself (Norris et al., 2016). Interdisciplinary research (IDR) means "a process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline" (Klein & Newell, 1997, p. 3). Transdisciplinary research (TDR) goes a step further and implies "a purpose-driven collaborative process of knowledge production among researchers of different disciplines, inter- and trans-disciplinary fields, and representatives of private and public sectors including civil society"

(Pohl et al., 2021, p. 18). 'Integration' thereby stands at the core of both IDR and TDR and intends to create new or more comprehensive knowledge about a complex problem and potential strategies to address it (Hoffmann et al., 2017a).

Several actors, such as research institutions, funders and international organizations acknowledge the necessity of ITD initiatives for coping with the sustainability challenges of our time (OECD, 2020). Yet, the envisioned integration of diverse knowledge fields still faces major challenges, and ITD initiatives might not have realized its full potential yet (Arnott et al., 2020; Schuitema & D. Sintov, 2017). While there have been significant advancements in the ITD literature concerning contextual conditions for ITD in general, there is less literature on these conditions for ITD integration in particular. In addition, several authors highlighted the need for more empirical work examining the complex interrelationships between those contextual conditions at different structural levels (Institute of Medicine, 2005; Siedlok & Hibbert, 2014) or 'systemic arenas' (Friis et al., 2023). We therefore ask:

1. What contextual conditions at different structural levels influence ITD integration?
2. How do these structural levels interact with each other, and thereby influence ITD integration?
3. How can different actors create favorable conditions for ITD integration?

We studied these questions in two large ITD research programs and one transdisciplinary network in Switzerland by examining the perspectives of both program/network leaders and members via interviews, workshops and participant observation. The interviewees shared experiences from both ITD integration endeavors of their past as well as their current ITD program/network. With this paper we intend to look at the ecosystem in which ITD integration takes place, considering both relevant conditions at different levels (structures) and actions by different actors (agency) to make integration happen. In the following, we will first define ITD integration (5.2.1.) and briefly examine existing approaches to conceptualize contextual conditions of ITD integration and which actors can shape integration (5.2.2.). We will then present an analytical framework on ITD integration (5.3), which allows us to embrace a comprehensive perspective on ITD integration by considering both structure and agency. This is followed by describing our case study design and methodological approach (5.4.) and presenting our empirical insights with the help of the framework (5.5.). We conclude with practical implications for different actors (5.6.) and a call to action to create more favorable conditions for ITD integration.

5.2. The ecosystem of inter- and transdisciplinary integration

5.2.1. The concept of inter- and transdisciplinary integration

Integration is considered to be both the core characteristic as well as the key challenge of ITD initiatives (Klein, 2012). There exist many different definitions and notions of integration, which make it

imperative to be clear about its definition (O'Rourke et al., 2016). Integration stems from the latin word 'integrare' which means 'to refresh/to renew, to make whole' (*Oxford Latin dictionary*, 1982, p. 935). We define integration as a complex interactive *process* where different and previously unrelated perspectives, knowledge pieces or ideas from either different disciplines and/or across science, policy and practice are connected with each other and assembled into something new (Boix Mansilla et al., 2016; Eigenbrode et al., 2017; Pohl et al., 2021). Integration is inherently multidimensional including at least a cognitive (e.g. integrating different concepts, methods, etc.), social (e.g. harmonizing working routines and expectations) and emotional dimension (e.g. creating a respectful learning atmosphere) (ibid). An integration process can result for instance in a more comprehensive or transformed understanding of a social-ecological issue (*outcome*), or an integrated product or service such as a new tool, method or approach to a sustainability problem (*output*) (Pohl et al., 2021). Consensus is only one of several possible outcomes as integration might also take place between just two or three individuals of a group, and might be one-sided or mutual (Pohl et al., 2021). In this paper, we use the term 'integration' more broadly, referring to both the practice of integrating knowledge, people and their related expectations, interests and needs (process), as well as its potential results (outcomes, outputs). It is key to emphasize that integration is not an end itself. Integration becomes necessary when the object of study is multi-faceted and its facets cohere (Newell, 2001, p. 2), and when the purpose of the study requires to take the different cohering facets into account (Boix Mansilla, 2006). This for instance applies in the case of climate change, pandemics or transformations towards sustainability where biophysical aspects are strongly intertwined with social-psychological, political and economic aspects.

5.2.2. Understanding contextual conditions and the role of actors in shaping ITD integration

Whether ITD teams can live up to the integrative ambitions of their programs and networks depends on the overall contextual conditions under which integration takes place. The term 'condition' refers to *circumstances*, hence situational factors which influence the performance of a team and the outcome of a process (Oxford University Press, 2021). Conditions can possess both enabling and hindering causal powers (Hartwig, 2007). However, the term also entails the notion of a *prerequisite*, hence the "circumstances without which something can't exist" (Danermark et al., 2002, p. 96).

There is extensive literature on enabling and hindering conditions of ITD in general (Ding et al., 2020; Guimarães et al., 2019; Nurius & Kemp, 2019; Stokols et al., 2008; van Rijnsoever & Hessels, 2011), while less studies focus on such conditions for ITD integration in particular (Hoffmann et al., 2017a; Jakobsen et al., 2004; Tress et al., 2007). However, many of the contextual conditions for ITD in general also lay the foundation for being able to work towards integration in the first place. Therefore we conclude that conditions of ITD in general are also very relevant to integration in particular.

Key contextual conditions highlighted by several authors include the role of personal characteristics, skills, attitudes and 'habits of mind' of individual team members (Bruce et al., 2004; Horn et al., 2022;

Jakobsen et al., 2004; Nurius & Kemp, 2019; Salazar et al., 2012). Others discuss how individuals can acquire crucial skills to engage in ITD either early on in undergraduate and graduate programs (Bernert et al., 2022; Di Giulio & Defila, 2017) or through 'training on the job' and self-reflective tools during their career (Claus & Wiese, 2021; Schuitema & D. Sintov, 2017). Several authors have stressed the importance of an overall team's readiness to collaborate across boundaries in order to truly work in an integrated manner (Armstrong & Jackson-Smith, 2013; Freeth & Caniglia, 2020; Hall et al., 2008). This includes effective group communication (Hall & O'Rourke, 2014; Thompson, 2009), mutual respect between team members (Boix Mansilla et al., 2016; Stokols et al., 2008), and the development of commitment and shared ownership (Hoffmann et al., 2017a; Wine et al., 2022). Spatial proximity of team members, access to comfortable group spaces for face-to-face interactions (Jakobsen et al., 2004; Stokols et al., 2008) and the availability of technical support (Stokols et al., 2008) were found to be further influential conditions. Manifold studies argued that the discipline-focused structures, assessment and excellence criteria, and related allocation of funding, tenure and promotion policies in place are strongly shaping ITD initiatives (Blythe & Cvitanovic, 2020; Bruce et al., 2004; Institute of Medicine, 2005; Klein & Falk-Krzesinski, 2017; Lyall, 2019; Nastar et al., 2018). Finally, the overarching societal context such as the prevalence of a societal crisis demanding ITD or the existence of cooperative international policies were argued to be influential (Ding et al., 2020; Stokols et al., 2008). Other authors suggested to also examine the interlinkages between different levels such as between individual competencies and team dynamics (Nurius & Kemp, 2019; Pennington, 2016).

However, the ecosystem of ITD integration is not only set up by specific contextual conditions, but also comprises various actors. These actors can influence and shape the conditions and therefore also (the potential for) ITD integration through their actions. From literature on practical actions and recommendations for incentivizing ITD in general we found the following actors to have the strongest influence on integration in particular:

- individual team members such as researchers and societal partners from policy and practice (Ding et al., 2020; Jahn & Keil, 2015),
- program managers / leaders / integration experts (Hoffmann, Deutsch, et al., 2022; Horcea-Milcu et al., 2022; Jahn & Keil, 2015; Lyall et al., 2011),
- directors and/or executive board members of (research) institutions (Benson et al., 2016; Bolger, 2021),
- (research) funders (Arnott et al., 2020; Brown et al., 2015; Ding et al., 2020; Gleed & Merchant, 2016; Jahn & Keil, 2015),
- science policy-makers (Jahn & Keil, 2015; OECD, 2020).

To explicitly address the interplay between conditions (structure) and actions (agency) in our analysis, we propose an analytical framework that acknowledges this interplay and allows for diagnosing

different fields of tensions and deriving actor-specific entry points for actions. It is easier to navigate such fields of tension when one is both aware of their existence (Fischer et al., 2021, p. 10) and from where they originate.

5.3. An analytical framework for ITD integration: the interplay between structure and agency

The existence and interplay of specific conditions creates overarching patterns, which are overall rather favorable or unfavorable to integration. We call this configuration of conditions structures (Sharar, 2016). One can approach ITD integration by either looking at these structures under which it takes place or by looking at the relevant actors (agency) shaping or contributing to integration. The distinction and the relationship between structure and agency has been a highly debated topic in the realm of social sciences (Elder-Vass, 2010). From a conceptual and analytical point of view, it makes sense to distinguish them although they are strongly intertwined and influence each other in practice (Hartwig, 2007): Distinguishing them helps us to understand how structures influence the practice of actors, as actors are always confronted with pre-existing structures (Danermark et al., 2002). At the same time, structures only persist as long as actors reproduce them, hence actions also have the power to transform structures (Kempster & Parry, 2011). We argue that a holistic view on ITD integration therefore needs to assume a dialectical interplay between structures and agency (Fleetwood, 2005). Our analytical

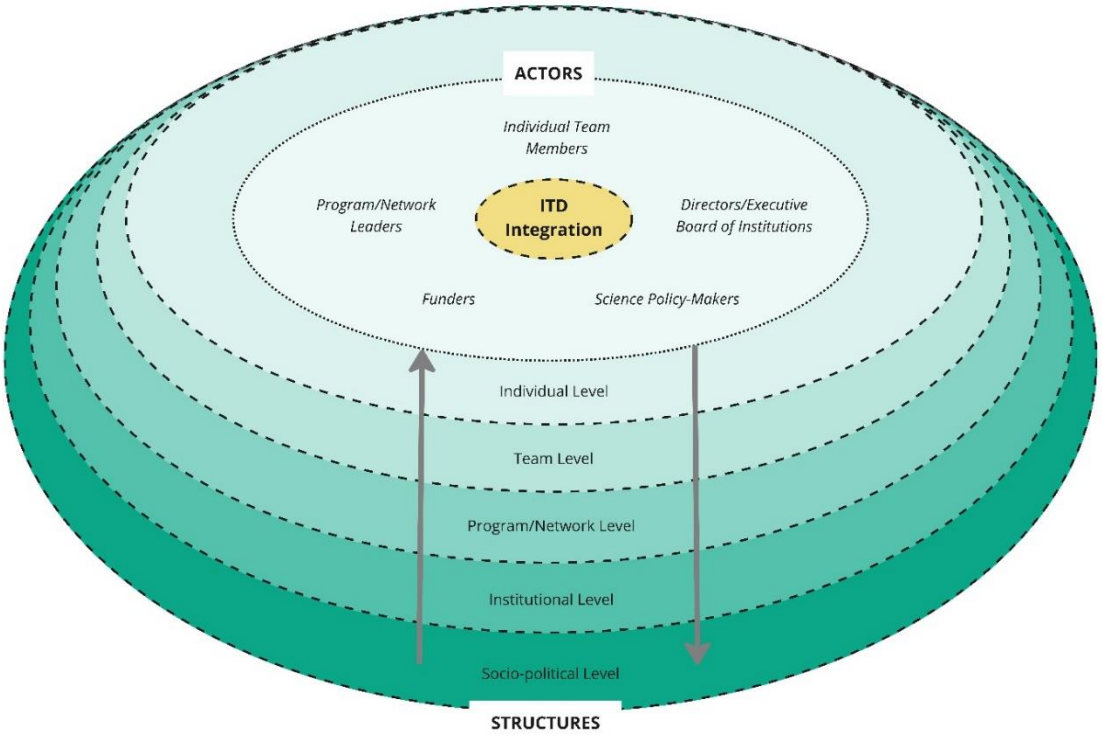

Figure 3: A holistic view on ITD integration: the interplay between structures and agency (own elaboration)

framework (Figure 3), distinguishes the following levels: the individual, the team, program/network, institutional and the socio-political level[9]. Other authors have chosen similar analytical levels when evaluating ITD endeavors, and deriving recommendations for actions (Armstrong & Jackson-Smith, 2013; Ding et al., 2020; Friis et al., 2023; Jakobsen et al., 2004). We advance this conceptualization by employing a critical realist lens and arranging them as nested spheres (Danermark et al., 2002). This should not suggest any hierarchical order in the sense of 'one sphere has more power over the other', but shows the embeddedness of the different levels. In addition, each level is not a closed system, but influences the other spheres in a non-linear way. We think such a conceptualization provides a more comprehensive view on ITD integration, allowing us to understand the interplay between different structural levels as well as between structure and agency. In the result and discussion chapter, the framework will be used for presenting and discussing our empirical results, and deriving implications for different actors.

5.4. Research design

5.4.1. Case studies

To answer the research questions we analyzed three case studies: (1) the ITD program *Wings* (Water and sanitation innovations for non-grid solutions) at Eawag (Swiss Federal Institute of Aquatic Science and Technology), (2) the ITD program *Extremes* at WSL (Swiss Federal Institute for Forest, Snow and Landscape Research), and (3) the transdisciplinary network *NCCS* (Swiss National Centre for Climate Services) based at MeteoSwiss (Federal Office of Meteorology and Climatology) (see Table 5, below). The three case studies face similar challenges with regard to integration, but differ in their set-up, start and duration. The rationale behind choosing diverse cases was to come to a comprehensive view on integration in ITD programs and networks. All case studies deal with multi-faceted social-ecological topics and go beyond an 'additive' effort but create integrated outcomes and outputs. The two ITD programs Wings and Extremes were initiated from within the respective research institutes Eawag and WSL with the intention to foster synergies across disciplines, projects and departments while also considering the needs from policy and practice. At the program level, the focus tends to be more on interdisciplinary than transdisciplinary integration. The NCCS was initiated with the intention to foster integration across different Swiss federal offices as well as between the federal level and academia in

[9] The individual level: Integration cannot happen without individuals productively working towards it; the team level: The interplay of individuals give rise to certain dynamics influencing integration; the program/network level: Each program/network is set-up in a certain manner favorable or unfavorable to integration; the institutional level: Individual behaviors, team dynamics and program/network activities are influenced by the involved institutions; and the socio-political level: Societal crises can provide a purpose for integration in the first place.

Switzerland in order to produce solid knowledge bases for climate change adaptation for a broad range of end-users.

Table 5: Characteristics of the three Swiss case studies

	Wings (Eawag)	Extremes (WSL)	NCCS (MeteoSwiss)
Topic	Sustainable urban water management	Future extreme events	Climate services
Duration	2016-2022	2021-2025	2015 - not yet defined
Aims	To study and develop novel non-grid water and sanitation systems in diverse socio-economic contexts by fostering ITD integration across four Eawag departments, multiple disciplines and diverse projects	To study current and future extreme events impacting society and the environment by fostering ITD integration and equip Swiss actors with appropriate decision-making tools and coping strategies to address future extremes	To develop, bundle and disseminate climate services by functioning as an interface between producers and users of such services and promoting ITD integration between Swiss federal offices and Swiss research institutions
Key challenges	• To identify and make use of synergies between individual projects with different time horizons and funding sources • To link abstract and case-specific knowledge within and across different socio-economic contexts (e.g. Switzerland, US, India)	• To lead integration across five different projects at the program level and support integration processes on the project level • To develop user-centric and actionable products for involved Swiss actors from policy and practice on project and program level	• To incentivize collaboration across individual federal offices and academia • To produce, process and translate scientific findings into user-centric and actionable climate services
Commonalities	• Co-Leadership (Main leader & deputy) • Addressing socio-ecological challenges and developing coping strategies and solutions • Context of involved main institutions: Switzerland • Strive for ITD integration		
Differences	• Fosters integration across projects funded by external and internal funding • Initiated bottom-up by interested researchers from different Eawag departments • Context: Diverse socio-economic contexts	• Fosters integration across five, to a certain extent very different projects • Initiated top-down via funding provided by the WSL directorate • Context: Both Switzerland and global context	• Fosters integration across individual federal offices and academia • Initiated bottom-up by representatives of federal agencies and research institutions • Context: Switzerland

5.4.2. Methods

We used different qualitative methods (semi-structured interviews, participant observation, and focus groups) which informed and built on each other (Flick, 2002). A first round of interviews was conducted with the six leaders, i.e. the main lead and deputy lead of each case study, followed by a second interview round with six to eight members from each of the three case studies (i.e. in total 28 semi-structured interviews were conducted, duration approx. 90 minutes each). Members were selected to represent a broad range of perspectives from diverse backgrounds (i.e. social, natural and engineering sciences), including researchers and professionals who (a) were at different points of their career, (b) occupied different hierarchical positions, (c) had different (intrinsic and extrinsic) motivations to join

the ITD initiatives, (d) different levels of prior experiences with such initiatives and (e) either led the initiatives (leaders) or contributed to ITD integration (members).

Further insights were gained through informal talks and participant observations, hence attending the program's and networks internal meetings, public events with stakeholders and program/network retreats several times per year (comprising about 50-60 participants). In addition, four focus groups were conducted with the six leaders of the three case studies on different themes which had emerged through the interviews and participant observation. All interviews and focus groups were recorded, transcribed, and analyzed with qualitative content analysis, employing inductive and deductive coding iteratively to derive overarching themes and identify commonalities between the case studies (Glaser & Strauss, 1967). This meant that the material was first analyzed through open coding guided by the question 'What influences ITD integration according to the interviewees?', followed by a selective coding based on our analytical framework. The latter meant assigning the emerging influential conditions to different structural levels (Holton, 2010) and identifying actor-specific entry points for action.

5.4.3. Accompanying research and authors' roles

The lead author of this paper conducted accompanying research (AR) in these three contexts for two to four years. Overall, the aim of this AR was to produce knowledge about integration processes taking place within those programs and network, called 'meta-type research' (Defila & Di Giulio, 2018b). However, the lead author took different roles in the different case studies. Within *Extremes* and *NCCS* the role of the lead author was to be an investigator, not an evaluator or integrator with regard to the content-specific activities of the initiative (Weith et al., 2019). Within the case study *Wings*, both the lead and the last author performed an integrative role as leaders of this ITD initiative and the respective integration process [hidden reference]. Performing different roles across the case studies constituted a unique learning and research opportunity to the lead author. She was able to gain in-depth insights by being confronted with the challenges of leading ITD integration on a daily basis and experiencing different structural fields of tension over four years herself (Wings), while also taking a more distant observer view in two other contexts for two years (Extremes and NCCS) making it possible to contrast experiences across contexts and reflecting upon them. Such a combination of the practice and the scholarship of integration was also argued by Lemos et al. (2018) to be a particular fruitful approach for understanding how ITD integration works in practice. To balance the potential bias by the first and last author with regards to the case study Wings, the second and third author of this paper critically reviewed and checked the analysis.

5.5. Results

"*Everyone is enthusiastic, they think it's good to work together, they are even more enthusiastic where they can bring their own agendas forward and they are grateful for the money. And when you write such a joint proposal, where it says that everything will be well integrated together, everyone is also enthusiastic; and then to manage to really live it, that is now the challenging part.*" (SM)

The empirical material sheds light on conditions at different structural levels, which influence ITD initiatives when working towards integration. We systematize these conditions by applying our analytical framework (Figure 3). In order to protect the confidentiality and anonymity of the interviewees and their respective program/network, we only distinguish between leaders (L) and members (M), and in the latter case between Seniors (SM) (e.g. department heads, professors, group leaders, employees with leadership responsibilities) and Juniors (JM) (scientific assistants, PhDs, PostDocs, employees without leadership responsibilities).

5.5.1. Individual Level

5.5.1.1. No blooming meadows all the time: being aware of personal investments and benefits

Both leaders and members stressed that many exhausting discussions during integration processes "*have to do with the fact that many people could not really imagine what it means to work in a transdisciplinary manner*." (SM). Interviewees emphasized that the involved individuals need to have a realistic understanding about what personal investments doing integration entails, and what personal benefits might be gained:

"[It is key that the involved people] do not underestimate how much they have to invest personally, but also that they don't overestimate the benefits that come from it... Because that's just not blooming meadows." (SM)

Setting the stage for ITD integration was reported to entail among others explaining concepts one has taken-for-granted an entire career – an investment that might be considered 'annoying', but is key to building up a common understanding among the team (SM, AP1[10]). Creating this common understanding and clarifying each other's needs is usually not done via a single meeting nor via email. It requires investing considerable time (JM, AP2) and meeting face-to-face to avoid that an ITD initiative breaks apart along the work package boundaries (that are usually structured along disciplines or sectors), as one interviewee reported from a past project:

"*Before having this meeting we were trying to ping-pong via email... I was producing things, but it was not exactly what they needed. Then I called for a meeting, "Let's sit together and realize what you*

[10] AP refers to the related quote in appendix B

really need."…I had to do a bit more of things that I didn't really need to achieve my own goal, so that the other was able to use them. But it worked well." (SM)

Although it is well established that there are substantial transaction costs attached to ITD initiatives (Goring et al., 2014), our results show that the required investments still tend to be underestimated in practice. In line with Eigenbrode et al. (2017), we argue that it is key to make these investments, but also potential benefits explicit (Howarth et al., 2022) and discuss them early on. Ideally they are made explicit before people join an ITD initiative, so they can reflect and make a conscious decision whether they will be able and willing to deal with these transaction costs. Especially time for face-to-face encounters are key in order to reveal flawed assumptions about each other's (knowledge) needs. Our findings complement existing research that digital communication is only a supplement rather than a substitute to face-to-face communication (Gruber et al., 2022; Jakobsen et al., 2004) as in-person social interactions are essential for mediating and processing differences in ITD teams (Lerchster & Lesjak, 2014, p. 89).

5.5.1.2. Divergence from business-as-usual: integration means doing things differently

As ITD initiatives are different from disciplinary or sectoral ones, it requires individuals to diverge from their routines and to engage differently in such contexts. The interviews indicate that individuals need to consciously shift roles, which can be especially challenging for senior scientists/professionals. This entails for instance shifting from being a department head or professor to being a collaborator in an ITD initiative:

"*As head of the department, you have a role like you always know something about everything. You always know best, or you certainly know something about everything… But now in the [program/network] role, I don't have that approach. There I am more like.... maybe I don't know anything about it. Or I have to think about it more carefully."* (SM)

Such a role shift also requires individuals to give up control to a certain extent (SM, AP3) and leave familiar paths, explore and accept new approaches or methods although they might diverge from the usually 'way of doing things':

In the proposal we have now introduced [a new method] as an idea. I don't know how that works, but [person X] has already done it. To be able to let go and say, okay, we'll do it this way, even if I don't know in detail what that means." (SM)

One interviewee enthusiastically reported positive experiences when they managed to give up control and let the integration process evolve in an open-ended manner during an interdisciplinary workshop. Initially planned to rather validate their ideas, the results surprised them and were more innovative than expected (JM, AP4). As this anecdote suggests, moving from merely 'validating one's ideas' to truly integrating knowledge, requires individuals to display integrative behaviors. The interviews indicate

that integrative behavior entails demonstrating genuine mutual appreciation, engaging collaborators on eye-level instead of subordinating them into a service-role and being open to iteratively build on each other's contribution. Living up to these ambitions however sometimes proved challenging in practice as was reported from past ITD projects (SM, AP5) and as individuals "must balance the need to contribute as experts with the need to learn as students" (O'Rourke & Crowley, 2013, p. 1939). We argue that integrative work can be compared to engaging in 'nonroutine tasks' (Schmutz et al., 2018, p. 753), which are characterized by higher levels of ambiguity and uncertainty and therefore push individuals out of their comfort zone as work flows and habits need to be realigned with collaborators (ibid). Our findings indicate that it is key to support individuals in diverging from their business-as-usual and in learning how to genuinely engage in integration processes (Deutsch et al., 2021; Freeth & Caniglia, 2020; Horn et al., 2022; Steger et al., 2021; Ward et al., 2019).

5.5.2. Team Level

5.5.2.1. Constructive group atmosphere: assembling a team beyond disciplinary expertise

Assembling an ITD team was described to be more than just a matter of bringing excellent experts into one room. Interpersonal chemistry, trust and a positive group atmosphere are equally key for integration processes (SM, AP6; JM, AP7). It was observed and experienced that deconstructive individuals, especially in higher hierarchical positions, can cause severe damage to an integration process resulting in frustrating power games and an overall downward spiral within the team (SM, AP8). While having constructive individuals on board is beneficial for any collaborative effort, it might be even more important to ITD teams due to the extraordinary efforts they have to make in the first place, as one leader suggests:

"*I think integration really requires a great willingness to get involved with the other person, but also with the other person's way of working and thinking. And because that's time-consuming and exhausting, it kind of almost requires that you enjoy spending time with the other person. That you make the sacrifice, so to speak [laughs]. If it has to be a sacrifice, then it has to be fun at least."* (L)

However, interpersonal chemistry was found to be not the only factor that needs to be considered. Complementarity of team members is equally key:

"*My experience is that it is extremely dangerous when you have projects, which you set up with people you like very much and with whom you like to discuss very much, but without the mutual necessity. I'm a fan of working with people where [it is clear] if that person wasn't there, then I couldn't do it, then I'm really missing something."* (SM)

Our findings indicate that team composition is crucial in an ITD initiative. While we agree that a fruitful ITD team can also be built along the way through careful process design and leadership

(Schauppenlehner-Kloyber & Penker, 2015), our findings add that it is also key to pay attention to the initial compositions (Defila et al., 2016) or 'Phase 0' (Horcea-Milcu et al., 2022). This also echoes the work by Szostak (2017) and Norris et al. (2016) who advice to take collaborative skills and prior experience with ITD into account when composing an ITD team. We extend these findings and suggest that it also requires constructive people in a team, who complement each other to make integration thrive. We argue that – although it may appear trivial – in particular constructive team members constitute an essential component of psychological safety central to integrative work. If people feel psychologically safe, they are more likely to take risks, share and contribute ideas to achieve collective goals, provide feedback and admit mistakes (Edmondson & Lei, 2014, p. 36). While this is essential to mono-disciplinary/sectoral team endeavors too, we argue it is even more important to consider this social-emotional aspect (Boix Mansilla et al., 2016; Cairns et al., 2020) in ITD team composition thoroughly due to the overall greater potential for tensions in ITD teams (Loibl, 2005).

5.5.2.2. The critical mass: balancing intrinsic and extrinsic motivation in ITD teams

Interviewees joined ITD initiatives for several reasons. Some reported to be interested in learning from other fields and broadening their own horizon, not only for their career, but also for their personal development. Others are strongly motivated to contribute to a larger good, which can only be achieved by getting out of the 'tunnel vision' and teaming up with experts from other fields. Having such a critical mass of intrinsically motivated team members, who are willing to work towards a common goal and to share credit (SM, AP9; L, AP10), was found to be a key condition for ITD integration on the team level. Others also perceived the ITD initiative as an opportunity to drive personal disciplinary or sectoral interests forward. Even if there is nothing wrong with this in principle and ITD collaborations ideally also yield disciplinary or sectoral fruits, it becomes difficult when self-interest comes to the fore too strongly and starts eroding trust in the group. A strong presence of hidden agendas was observed and reported to be counterproductive for integration in general, and for team dynamics in particular:

"*This situation, where you simply notice that a person is really only interested in his or her own box. To get a paper out of it, or a job. Or to get more money for some research. And then the person tries to position [themselves] somewhere in this crowd and to kick around with [their] elbows. In other words, they try to carve out a niche for themselves. I find that quite annoying."* (SM)

Extrinsic incentives such as receiving funding for ITD initiatives was perceived as another strong motivator for doing ITD as one senior member reports from a past project:

"That was simply the wish of [funding body X]…if one would like to have money for a large program, then one must have [people from discipline X] on board. Then we called those we know through some committees and said, "are you going to participate?" and then "oh yes, how much money will we get? Oh, that's great." (SM)

The empirical material indicates a certain risk that individuals join ITD initiatives because of increased funding possibilities and doing ITD research has become 'en vogue'. Cairns et al. (2020, p. 1711) argue ITD might have become a buzzword, serving as a "password to securing funding and influence; meanwhile, it often remains opaque what is actually done under its auspices". We found that mere extrinsic incentives alone are not a sufficient condition for mobilizing efforts to making integration really work in practice (SM, AP11). While funding is key for realizing integrative ambitions, we argue that it also requires a critical mass of intrinsically motivated individuals (Proctor & Vu, 2019) who are willing to share the spotlight and are driven by a common purpose (Boix Mansilla, 2006).

5.5.3. Program/Network Level

5.5.3.1. Better not a matter of passion: assigning explicit resources for doing ITD

A common challenge among all case studies was the mobilization of enough time resources for properly engaging in integration processes on the program/network level (SM, AP12). Several interviewees reported that although they are strongly convinced that integration is absolutely essential for addressing wicked problems, they lack the time to contribute to it. Resources sometimes exist only on paper, or are not explicitly stipulated in their work assignments (SM, AP13). This bears the risk that contributing to integration processes becomes a question of passion:

"We don't really have any specific resources to manage this, or just very much on paper and so on. You have to do it a little bit on the side with passion." (SM)

Even when willingness and intrinsic interest are in place, integration still tends to be pushed to the back (JM, AP14). It was both reported and observed during meetings that there are usually many good ideas for joint integrative activities (e.g. writing a synthesis document, policy brief, setting up a joint workshop with stakeholders), which are then discussed back and forth during several meetings, but then don't get implemented because members refrain from taking over tasks related to integration due to their already high work load: "*At the moment when [integration] really gets going, you then withdraw again*" (L). In sight of the difficulty to make time for properly engaging in integration processes, one interviewee suggests for the future:

"If one applies for resources in the future [for such a network/program], one should immediately consider, what does it mean for those, who are expected to contribute … Otherwise it depends on the motivation of the person only, right?" (SM)

These results are strongly interrelated with the presented insights in subchapter 5.5.1. (individual level) and align with the work by other authors that an ITD initiative can only be successfully run if both leaders and team members have sufficient resources at their disposal to properly engage in integration (Boone et al., 2020; Howarth et al., 2022; von Wehrden et al., 2019). It is therefore advisable to reflect

prior to joining an ITD initiative to what extent those who are expected to contribute can actually mobilize the necessary resources (Kruijf et al., 2022).

5.5.3.2. The priority question: moving from nice-to-have to must-have

Resource availability is strongly related to the priority question. Several interviewees suggest that integration tends to be pushed to the back because it is viewed as a side-task and not a top priority by collaborators above all in higher hierarchical positions (SM, AP15). One member explains:

"*So the will is often there, but everyone is so busy with their core tasks that they can't look to the left and right or get out of their own little garden.*" *(SM)*

Several interviewees also pointed to the inner conflict and ambiguity of the need to delegate previous tasks in order to have enough capacities for dealing with new tasks such as participating in an ITD program/network (SM, AP16). Whether people contribute to integration or not, was reported to depend on their workload in their core business (SM, AP17). One leader suggests:

"You have to reach your [project] targets. You have to get your data together and your publications and then show a poster at the annual event. And that's just the most important thing, or the only criterion that counts for most people, and everything else is extra." (L)

One member adds to this by explaining what s/he considers his/her core job:

"*It's always relative whether you can make time. I can cancel something else. So, it's such a priority change. I don't necessarily see it as my core job to do that. I'm doing it on top of things. Maybe that's the fundamental problem. So if I had nothing else to do but devote myself to the [program/network], then I would do that much more intensively, but that's not the case. I have a whole research group to lead. I have PhD students to supervise. So I have to devote that time, that's my responsibility."* (SM)

Our findings indicate that ITD integration needs to shift from being a nice-to-have to a must-have, at least while being part of an ITD initiative. If individual team members do not perceive integration as part of their "real job" (Armstrong & Jackson-Smith, 2013), integration will steadily slide down the priority list and become a matter of chance. One way forward is to assign integration a higher weight at program/network or institutional level by allocating more resources to the individuals involved while also including and creating explicit positions for integration experts, i.e. experts who lead, manage or advise others on ITD integration (Hoffmann, Deutsch, et al., 2022).

5.5.4. Institutional Level

5.5.4.1. What you promote is what you get: the role of incentive and assessment systems

Several interviewees stated that the common perception of integration processes as 'nice-to-have' is related to the current incentive system in place at (research) institutions (SM, AP18) and the overall academic system which discourages people to engage in ITD integration:

"Group leaders are caught up in their disciplinary constraints, problems and incentives, so it doesn't make any sense at all for them [to invest in ITD integration]." (SM)

One interviewee emphasizes that although his/her institution values ITD integration more than previous employers, career-wise it would probably still be better to avoid ITD efforts:

"Promotion, academic recognition are linked to key performance indicators, and it's an explicit fact that, every minute I don't now spend on a paper in a particular journal, that this is simply recognized or branded as a stupid waste of time. And one shouldn't underestimate that." (SM)

The current structures were described to make it still easier for disciplinary researchers to develop an academic career than for ITD researchers (L, AP19), as the current reward systems incentivize researchers to go for 'more of the same', digging even deeper instead of thinking broader:

"So you don't get rewarded academically in this area, it's much easier to just incrementally cut off another salami piece, to look even deeper into the details… a narrower and narrower understanding of a narrower and narrower field." (SM)

This lack of academic recognition for the substantial efforts inherent to ITD integration is perceived as extremely unsatisfactory by some researchers, as a large part of their daily work then is considered a mere 'nice-to-have' and not a 'must-have'. Along these lines, one interviewee argued:

"We need a very fundamental discussion of what 'impact' actually means, or what is meant by when someone has done something 'relevant'?…What we are doing at the moment is optimizing an H-index without knowing whether it says anything at all. So of course it says something, but maybe it's not what we want." (SM)

The H-Index was described to be an excellent illustration of Goodhart's Law: when a measure becomes a target, it ceases to be a good measure. Instead of unreflectively chasing behind an H-index, the relevance or impact of an individual's work could also be assessed against addressing or alleviating a specific societal problem. However, our findings indicate that the established assessment criteria are still geared towards disciplinary excellence and a one-person show, making ITD integration still a 'high-risk, high-reward endeavor' (Kilburn, 1990; Leahey et al., 2017). Institutions should therefore cushion these risks or not make them risks in the first place by aligning assessment criteria, and calibrating the

tender and funding clock (Benson et al., 2016; Institute of Medicine, 2005, p. 91; Schuitema & D. Sintov, 2017).

5.5.4.2. Keeping your back free: the support of superiors and the host institution

Several interviewees emphasized that integration requires openness and willingness to take risks not only from leaders and individual team members, but also from their host institutions and superiors:

"*I think it also needs openness from your institution...a boss who is completely open about how something like this should be organised. S/he also told me at the beginning that s/he'd rather prefer we try something new and then fall flat on our face, because there's a lot of perfectionism in our department."* (L)

Another member adds the aspect of freedom and "unstructured thinking":

"*I used to work in science, and there you have freedom and you can think about a question. In most cases you don't have a professor breathing down your neck and telling you what you are going to do now. From that point of view, in the federal offices a culture is needed where unstructured thinking about certain questions is also allowed.*" (SM)

However, whether a program/network member can engage properly in integration processes depends on whether his/her supervisor has an understanding of the relevance of integration and the time and energy it demands (JM, AP20). One member feels privileged that his/her superior appreciates integrative work and related activities, stressing that not everyone in his/her institution necessarily does:

"*I'm lucky that we have such a culture in our department. Sometimes I feel a pressure to justify myself, so for a long time we were ridiculed as the 'workshop department', because we have workshops all the time, but my boss knows that and thinks it's important and keeps your back free, which is very importan*t." (SM)

Our findings indicate that ITD integration requires an institutional culture which values unstructured thinking and experimenting, and assigns relevance to integration. This entails the backing by reflective superiors, who are aware of the substantial efforts inherent to ITD integration.

5.5.5. Socio-political level

5.5.5.1. Enthusiasm meets stumbling blocks: addressing administrative and legal barriers

When trying to foster integration across institutions, leaders and members reported that the structures are currently set up in a manner which do not easily allow for integration:

"We walk on new territory almost every day…, because the federal level is not really designed to work together. Of course they work together, but when it comes to 'pooling' funds, setting up joint projects …that is all quite new." (L)

One interviewee reported that time which was initially estimated to be used for working on content, now had to be invested in dealing with legal stumbling blocks, which led to unexpected time delays as a result (SM, AP21; SM, AP22). Due to the 'tight corset' of rules about how money is allowed to be spent and how calls need to be designed, integrative ideas might have to be downscaled or cut (SM, AP23). For managing and overcoming structural stumbling blocks, additional human resources became necessary:

"*We are not familiar with these, to put it bluntly, technocratic details... And that's why it's all the more important to have people like X, who really takes charge of it and coordinates everything and makes all these clarifications with the various offices, which wouldn't have been possible without really hiring someone who could do nothing else but that.*" (SM)

Several interviewees stressed the need to learn from this experience and adapt structures and rules in order to make integration easier in the future. One way would be to institutionalize them within and across institutions (L, AP24)

Our findings mirror the work by Dressel et al. (2014, p. 207) stating that carrying out cross-organizational ITD research is not one of the primary tasks for many internal or external university organizations. Therefore, often a new framework must be created for ITD collaboration. Vienni Baptista et al. (2022, p. 4) remind us that if ITD initiatives don't get institutionalized to a certain extent, much resources are spent on reinventing successful set-ups and arrangements. As we expect such cross-organizational initiatives to stay or even grow in the future, we suggest that instead of creating legal and organizational arrangements from scratch each time, one should aim for either harmonizing rules, come up with more flexible frames for cross-organizational collaborations or reduce administrative barriers (Kassab et al., 2018). In sight of budgetary constraints and cost-saving measures concerning public money, removing structural barriers on the long-term might allow for using synergies across institutions more effectively.

5.5.5.2. Top-down mandate and societal pressure: shaping integration from the top

It was reported that a certain political and societal pressure, often also in form of a political top-down mandate helps to push integration activities on program and network level (L, AP25). Along these lines, one interviewee reported that it motivates individuals, if a topic currently finds resonance on a societal level and gets political support:

"I also think it's beneficial that in the Swiss environment a lot of things currently happen [on the program's topic]. That it's a topic that has been taken up, also in the Federal Office X, and they have

now also invited to the kickoff to bring it in and discuss it there. I find it very stimulating to work on a topic where you have the feeling that it's relevant and that there is a demand for results." (L)

As the previous subchapters indicate, doing integrative work requires substantial resources (time and personnel), which often need to be pooled across departments within an institution or across institutions. Mobilizing resources for crises that are perceived as acute by the population and politicians (most recently the Covid-19 pandemic, the war in Ukraine) are often easier to justify than expenditures on crisis prevention, as one interviewee pointed out with reference to the war in Ukraine:

"So I don't think anybody is questioning the benefits of Fedpol or of the intelligence service right now, are they? Certainly not at the moment. In this political situation that we're in, right? But the added value of others, for example the preparatory work for a crisis..." (SM)

One interviewee stated that ITD integration for jointly tackling societal problems doesn't receive enough support from higher political levels. It was reported to require more legitimacy, visibility and financial resources from the top to be commensurate with the magnitude of the challenges ahead. At the same time they emphasized that bridging and transforming those siloed structures requires substantial time and it might be key to start small first and let such structures grow incrementally. Overall, the findings indicate that the current political and societal situation influences the legitimacy and support for integrative work on certain issues and less so on others.

5.6. Implications and recommendations

Our findings and analytical framework suggest that for making integration happen, it requires both certain lower level conditions (e.g. a critical mass of intrinsically motivated and constructive individuals) and higher-level conditions (e.g. favorable incentive structures and backing from higher hierarchical levels at the institutional level). Neither a top-down nor a bottom-up approach is enough, but it is the interplay between the two (Sharar, 2016), which makes integration happen or not.

However, the results also show that the different structural levels are strongly interdependent and therefore impact each other mutually. Favorable conditions on lower levels can be impeded by unfavorable conditions on higher levels: For instance an individual's willingness to diverge from the disciplinary business-as-usual (5.5.1.2.) can be counteracted through disciplinary incentive structures at the institutional level (5.5.4.1.). As Bennett and Gadlin (2019, p. 297) note, "[i]ndividuals recognize quickly when there is no institutional support for [ITD initiatives], and they turn their attention to efforts for which they will receive backing, especially as it is related to their career growth and advancement". Vice versa, the existence of funding for ITD initiatives and support from higher hierarchical levels will

bear limited fruits if it does not encounter intrinsically motivated individuals and a positive group atmosphere.

Similarly, we argue that changing conditions on one level can have trickle-down or trickle-up effects on other levels respectively. For instance, modifying assessment criteria and incentive structures on the institutional level, potentially have productive trickle-down effects on the individual and team level: As top-down support on the institutional level assigns value and status to ITD teams (Bennett & Gadlin, 2019), the individual's definition of what constitutes the 'core-business' might shift, potentially leading to a rearrangement of priorities and research agendas more favorable to ITD integration. Individuals and teams reporting to their superiors about their struggles to fulfill both disciplinary/sectoral and ITD integration tasks (bottom-up), in conjunction with higher socio-political pressure on institutions to develop more holistic answers to societal challenges as the Covid-19 pandemic (top-down), can influence awareness and action on an institutional level.

Our results do not claim determinism. This means that intrinsically motivated individuals are not completely locked-in by unfavorable structures, but can also disregard and act despite of them. Many have also done so given the increased number of so-called Integration Experts (Hoffmann, Deutsch, et al., 2022), Interdisciplinary Executive Scientists (Hendren & Ku, 2019), or Integration and Implementation Sciences Specialists (Bammer, 2013). However, it involves high costs and energy expenditure to swim against the tide, including the risk to perform poorly in the frame of disciplinary assessment criteria, to be no longer compatible with one's scientific or sectoral community or to leave the academic system due to the lack of ITD career paths (Guimarães et al., 2019; Hoffmann, Deutsch, et al., 2022). It is important to stress that our results neither suggest that ITD integration is doomed to fail if certain conditions are not 'perfect' nor that one should wait with an ITD initiative until the most favorable conditions are in place. For instance, transforming discipline-centered organizational structures may take time or might be opposed. In such cases, our framework can help to identify entry points for actions at other levels to balance tensions arising from the organizational structure. This echoes Bruun et al. (2005, p. 61), arguing that "two universities with the same organizational structures may end up in different research cultures depending on how fiscal decisions are made; how strategic planning is done; what management principles are adhered to; how quality is defined; how evaluation is performed; and how new faculty are recruited".

Overall, our findings imply that making integration happen in practice can neither depend on intrinsically motivated hard-working individuals only nor on integrative program/network leaders or any other actor alone that we identified. It is the conjunction of actions by these different actors at different structural levels and therefore also a shared responsibility between all of them to make integration possible. These efforts should be directed towards alleviating or transforming unfavorable structures into favorable ones and giving continuity to them through their actions. At the same time we

argue that leaders of ITD initiatives have a key role to play as they are positioned at the interface between lower and higher level structures, and can therefore mediate and build bridges between them.

To support this transformation process, we derived several key recommendations (Table 6) by linking the five key actor groups identified in subchapter 5.2. and 5.3. (Figure 3) to the empirical insights at the various structural levels presented in subchapter 5.5.. While some of the recommendations are directed towards ensuring certain starting conditions (e.g. team composition), others concern a more fundamental transformation of structures (e.g. incentive system). Ideally they are implemented in a concerted manner.

Table 6: Recommendations for actions to enable integration according to actor and structural level

Actors	Recommendations according to structural level	Supporting literature
Individual members	*(1) Individual level:* Be aware of the personal investments inherent to ITD integration; reflect upon your motivation and decide consciously if you are willing to make the required investments; perform a conscious role shift from being the PI or superior towards being a collaborator; be open to do things in a new way; display integrative behaviors by engaging your colleagues at eye-level instead of subordinating them into a service role. *(2) Program/Network level:* Treat ITD integration as a core-task (at least temporarily) and assign explicit resources to it. *(3) Institutional level:* Ask superiors for support before joining an ITD initiative and make explicit that substantial resources are needed.	Kruijf et al. (2022), Pärli (2023), Jahn and Keil (2015)
Program managers/ leaders / integration experts	*(1) Individual level:* Make sure that your team members have a realistic understanding about necessary personal investments and benefits; make clear that doing ITD means diverging from their routines and give concrete, tangible examples how this might look like; allow for enough face-to-face interactions. *(2) Team level:* Assemble your team wisely taking into account factors beyond disciplinary excellence such as interpersonal chemistry, and complementarity; be aware that the mere availability of funding should not be the main reason why people join the team; make sure that there is a critical mass of intrinsically motivated and constructive people in the team driven by a common purpose and willing to share the spotlight. *(3) Institutional level:* Report tension fields and daily struggles arising from the current assessment and incentive structures to the directorate or executive board of the involved institutions.	National Research Council (2015), Norris et al. (2016), Jahn and Keil (2015)
Directors / executive boards of institutions	*(1) Individual level*: Contribute to psychological safety by keeping the individual's team members and leaders' back free for experimenting and engaging in integration properly; provide and support opportunities for ITD capacity-building.	Boix Mansilla (2006) Kandiko and Blackmore (2008), Bark et al. (2016) Cairns et al. (2020)

	(2) Program/network level: Grant the program/network team explicit time resources and specific internal funds to incentivize integration; make explicit that integration is part of the core business (at least temporarily) and is a strongly desired must-have, not a nice-to-have; don't force ITD as it shouldn't be an end in itself, but requires a common purpose. *(3) Institutional level:* Revise your current incentive structure and assessment criteria, and analyze to what extent it is encouraging or discouraging ITD integration; implement measures which reward, acknowledge and give visibility to integration efforts.	Horn et al. (2022) (Klein & Falk-Krzesinski, 2017)
Funders	*(1) Team level:* Provide tips for team composition during funding calls; assess a proposal team beyond disciplinary excellence. *(2) Program/network level:* Be aware that extrinsic, monetary incentives are not sufficient for making integration work; ask applicants to make explicit what resources they will be able to mobilize to properly engage in ITD integration and what common purpose they pursue with their ITD endeavor; provide explicit funding for integration experts and reimburse travel expenses for face-to-face meetings; provide funding for ITD capacity-building and ask explicitly about an integration concept. *(3) Socio-political level:* center calls around societally relevant problems while still allowing the ITD initiative a certain degree of openness and autonomy.	(Arnott et al., 2020) Bark et al. (2016) Pohl et al. (2011) Cairns et al. (2020) Hoffmann et al. (2017b) Hoffmann, Deutsch, et al. (2022)
Science policy-makers	*(1) Program/network level:* provide substantial financial support and long time-horizons to research on societally relevant questions. *(2) Socio-political level:* promote collaboration and incentivize public and private actors to engage in ITD integration; support the harmonization of rules between different institutions and/or provide flexible frame for collaboration to avoid starting from scratch each time.	OECD (2020) Jahn and Keil (2015)

5.7. Conclusion

Integration stands at the core of ITD initiatives and is an inherently complex undertaking. Our results indicate what contextual conditions influence integration on the individual, team, program/network, institutional and socio-political level and how those structural levels are interlinked. We believe our analytical framework and empirical insights can (1) help diagnosing and illustrating where different fields of tensions come from, (2) support different actor groups in initiating, planning, leading, incentivizing, funding or reflecting upon ITD integration at different levels, and (3) demonstrate the need of concerted efforts by different actors for establishing favorable conditions for integration.

ITD initiatives can of course evolve differently and produce different effects depending on the context (Pärli et al., 2022). We are well aware that our empirical results stem from a high-income European country, characterized by well-funded universities and a particular socio-political context based on consensus and direct democracy. For this reason, our empirical results need to be viewed against this backdrop. However, by contrasting it with other studies in subchapter 5.5. and 5.6., we could observe that the identified fields of tensions are also present in other contexts. In addition, our analytical framework was derived through critical realist reasoning, allowing us to identify overarching structures producing certain tendencies. We do not claim any mechanistic, linear cause-effect relationships applicable to every context, but presented a holistic view on integration, which can be filled with context-specific empirics. We thereby intended to strike a balance between claiming strong generalizability and absolute context dependency. It is further to note that our empirical material largely stems from self-reported experiences (interviews, focus groups). Participant observation by the lead author of this paper and her double role in observing and experiencing structural tensions herself, provided an additional, complementary angle on the research questions (see 5.4.3.). Future research could apply the analytical framework in other contexts and further examine the interdependencies between different structural levels by combining both qualitative and quantitative methods.

To sum up, we argue that realizing the full potential of ITD integration should not be a matter of passionate individuals willing to swim against the tide. At the same time we do encourage individuals to proactively swim against the tide as structures can only be transformed through new or different actions. We therefore conclude this paper with a call to action by inviting individual members and leaders of an ITD initiative, directors or executive boards of the involved institutions as well as funders and science policy-makers to make use of the insights presented in subchapter 5.5. and the recommendations outlined in Table 6 in subchapter 5.6.. All together, these actions can create tail wind to ITD teams working towards integration at different structural levels. Because it is essential to remember: even when more favorable conditions are in place, ITD teams still need to deal with the ‘natural’ challenges of doing integration, such as finding common ground or bridging different perspectives. With the latter in mind, it is imperative to remove unnecessary stumbling blocks to ensure that ITD teams can focus on their natural challenges with full force and deliver the promise of addressing the urgent social-ecological problems of our time.

6. Herding cats - Integrative leadership strategies in inter- and transdisciplinary research programs (article 2)

Status and journal: Under review in *Sustainability Science*; revised and resubmitted

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Keywords: Leadership, Interdisciplinary, Transdisciplinary, Integration, Research Programs, Actionable Knowledge

Abstract: This paper focuses on the critical role of integrative leadership in inter- and transdisciplinary (ITD) research programs. ITD programs have become one of academia's responses to address contemporary sustainability challenges. Fulfilling the promise of such programs is extraordinarily challenging for all involved participants, but especially for program leaders who have to ensure that the perspectives of the involved program participants become truly integrated and that final and useful synthesis outputs are created. We present six core leadership challenges and respective strategies to address them in order to advance integration within ITD programs. These challenges include (1) mastering complexity and ambiguity, (2) advancing decision-making with lateral leadership, (3) ensuring responsibility and accountability, (4) setting program boundaries, (5) selecting suitable projects, and (6) dealing with misconceptions. We derived these challenges and respective strategies from both leading and studying in-depth three ITD programs focusing on sustainability issues in Switzerland. With this paper, we intend to promote awareness about the range of leadership challenges in ITD programs and provide actionable knowledge, which can support in particular fellow and future leaders, but also funders and heads of research institutions in their efforts to realize the integrative potential of such programs.

6.1. Introduction

Various studies have argued that inter- and transdisciplinary (ITD) integration does not happen automatically, but needs to be proactively led (Berger, 2019; Caviglia-Harris et al., 2021; Defila et al., 2006; Deutsch et al., 2021; Gray, 2008; Hoffmann, Weber, et al., 2022; Lyall et al., 2011; Oliver & Boaz, 2019). While interdisciplinary research intends to integrate the knowledge of different disciplines to address joint complex research questions (Klein & Newell, 1997), transdisciplinary research aims to integrate the perspectives of actors from science, policy and practice to address complex societal problems (Hirsch Hadorn, Biber-Klemm, et al., 2008). What distinguishes multidisciplinarity from inter- and transdisciplinarity is that the former does not include the proactive step of integration of different perspectives (Klein, 2010). We define integration as a process where different perspectives

are interacting with each other and assembled into something new (Pohl et al., 2021). Outcomes can include, but are not limited to, a new or more comprehensive understanding of a complex problem, novel solutions to such problems, or new institutional partnerships (Westberg & Polk, 2016). Outputs can entail, for example, inter- and transdisciplinary publications, policy briefs or synthesis videos tailored to different target audiences (including recommendations and potential ways forward) as well as new methods or tools (Hoffmann, 2024). 'Synthesis' is thereby one type of integration, which is pursued with the purpose of creating final integrated outputs or products (Hoffmann, Weber, et al., 2022).

Leading large-scale ITD endeavors has continuously evolved throughout the last years from being an avocational, on-top-of-things position towards a full-time position in itself (Defila et al., 2015). This can be explained, among other factors, by an increase in major ITD programs on supranational (e.g. Horizon 2020 or Interreg Alpine Space Program by the EU), national (e.g. the German Excellence Initiative, national research programs in Switzerland) (Defila et al., 2015; Kloet et al., 2012), cross-institutional (e.g. Joint Initiatives at ETH,) and institutional level (e.g. strategic focus areas by universities or institutes such as Extremes and Wings; see subchapter 6.2.). However, leading an ITD team through an integration process bears often underestimated challenges, as leaders need to make 'extraordinary efforts' (Volckmann, 2014, p. 254) on a cognitive level (e.g. bridging different disciplinary or professional knowledge fields, including their related languages, methods and logics) (Hendren & Ku, 2019), social-interactional (e.g. fostering a group identity, finding complementary team roles and dealing with different working styles and expectations) (Boix Mansilla et al., 2016; Hoffmann et al., 2017b; Klein, 2014), as well as emotional level (e.g. creating a positive and respectful atmosphere to ensure psychological safety) (Boix Mansilla et al., 2016). These efforts are essential in order for boundary-crossing ITD endeavors to thrive in their multi-dimensionality (Pohl et al., 2021). These challenges are further increased in the context of research programs, where program leaders not only need to ensure integration at the program level, but often also need to support it at project level. A research program usually comprises several projects, which are more or less related to each other and jointly contribute to an overarching goal or question (Hoffmann et al., 2017a; Schneider, Buser, et al., 2019). The compilation of several projects under one roof is a key strength of research programs as it has the potential to address such a goal or question from various angles. Accordingly, more robust contributions to addressing complex problems might be generated, if the leaders of such programs make sure that the involved individual projects do not diverge from each other and that the wide range of heterogeneous project results are integrated over time (Weith et al., 2019).

Leadership itself is a contested concept and has been approached from various angles (Blackmore & Kandiko, 2010, p. 57). This can be exemplified by the fact that the concept of 'leader' is sometimes equated with 'leadership'. Etymology suggests that there is a conceptual distinction between the two, defining the leader as the person who guides and shows a way forward (Barnhart & Steinmetz, 2000, p.

584), while the supplement "-ship" indicates a quality, condition or relationship between something (ibid p. 998). Hence, while 'leader' points to a certain position and a role characterized by certain competencies, attitudes and expertise, leadership is a multi-dimensional process of social influence oriented towards the achievement of a certain goal (Boone et al., 2020; Chemers, 1997, p. 5; Kempster & Parry, 2011). In this process, the individual leader plays a crucial role in setting and enforcing the boundary conditions for such integrative efforts and in triggering, enabling, and sustaining such efforts over time to attain such a goal (Harvey et al., 2018; Hoffmann, Deutsch, et al., 2022). However, realizing the potential of such integrative efforts is influenced by the interactions with team members, and other contextual factors (Chemers, 1997; Deutsch et al., under review; Kempster & Parry, 2011). Based on the distinction between leaders and team members, and insights from creative leadership research, we here define integrative leadership in ITD contexts as the process of mobilizing supportive contributions and integrating heterogeneous creative contributions from both leaders and team members towards a common goal (Mainemelis et al., 2018). Supportive contributions mean, "providing psychological, social, and material support for creativity" (Mainemelis et al., 2018, p. 4) while creative contributions entail generating, refining or linking new ideas (ibid). Integrative leadership is thus an interplay of creative and supportive contributions from both leaders and team members. However, it is up to the program leader to show a way forward and orchestrate the various contributions to achieve together with participants new and final creative outcomes and outputs (Mainemelis et al., 2018).

Interestingly enough, whereas "[l]eadership is one of the most widely researched and discussed topics in all areas of organizational sciences" (Yammarino, 2013, p. 149), there is scant literature on leading ITD programs in general (Defila et al., 2006) and even fewer empirical studies on leading integration in such programs in particular (Hoffmann, Weber, et al., 2022; Palmer, 2018). Given the importance of ITD integration in advancing sustainability studies (Kauffman & Arico, 2014; Lang et al., 2012; Polk, 2014), the increase of individuals (or small teams of individuals) taking over this role (Black et al., 2023; Defila et al., 2015) and the importance of leadership for attaining overarching program goals (Berger, 2019; Norton et al., 2022; Salazar et al., 2019), it is key to take a closer look at integrative leadership and how it is enacted in ITD research programs. This paper therefore asks:

What leadership challenges do leaders of inter- and transdisciplinary programs need to deal with during integration processes and what strategies proved fruitful to address them?

We explored this question in three ITD programs focusing on sustainability issues in Switzerland and provide both conceptual insights into integrative leadership as well as actionable knowledge, which can (1) support fellow and future leaders of ITD programs and larger ITD projects in their integrative efforts, and (2) provide insights for funders and heads of research institutions with respect to designing ITD program calls, selecting projects and setting up leadership structures. Thus, we position our article at the interface between the theory and practice of leadership in ITD research in general and integrative

leadership in ITD research programs in particular. We thereby contribute to the expressed need by various scholars in the field of ITD and sustainability studies to acquire a better understanding of their work realities within which they operate, including ideas on how to advance integration within their programs. For this purpose, this analysis aims at generating more empirical evidence to derive strategies and recommendations for enacting and supporting integrative leadership in ITD research programs (Bruce et al., 2004; König et al., 2015; Lawless et al., 2024).

For the purpose of simplification, we will subsequently only refer to 'leaders' when we refer to the individuals, who assumed the role of leading integration within the respective ITD programs, and use the term 'participants' when referring to the program team members. We distinguish between junior participants to refer to early-career researchers (i.e. Scientific assistants, PhDs, PostDocs) and senior participants to refer to team members with a higher hierarchical status, who are often superiors of the junior participants (i.e. group leaders, department heads, directorate members, etc.). We are well aware that in other ITD project or program contexts, the officially designated leader and the actual leader of integration processes (e.g. designated integration expert) (Hoffmann, Deutsch, et al., 2022) might not coincide. We believe that the six presented leadership challenges apply to these contexts as well. However, such a constellation might pose additional challenges, such as the need for additional interaction and coordination efforts between the official leader and the designated integrator.

6.2. Research design: case studies, methods and role of authors

A qualitative research design was used, as it allowed to explore in-depth how integrative leadership is practically enacted in three different ITD programs on sustainability issues in Switzerland and how the manifold challenges attached to it were addressed (Yin, 2014). The case studies include the ITD program *Extremes* at WSL (Swiss Federal Institute for Forest, Snow and Landscape Research), the cross-sectoral ITD program *NCCS-Impacts* within the network *NCCS* (National Centre for Climate Services) with the secretariat hosted by MeteoSwiss (Swiss Federal Office of Meteorology and Climatology), and the ITD program *Wings* (Water and sanitation innovations for non-grid solutions) at Eawag (Swiss Federal Institute of Aquatic Science and Technology) (see Table 7).

Table 7: Overview of the three studied ITD programs in Switzerland

Case Study	Extremes	NCCS-Impacts	Wings
Topic	Future extremes	Cross-sectoral climate impacts	Sustainable urban water management
Home Institution of Program Lead	Swiss Federal Institute for Forest, Snow and Landscape Research (WSL)	Swiss Federal Office of Meteorology and Climatology MeteoSwiss (host of the secretariat of the NCCS), together with six other Swiss federal offices of public health, of civil protection, for the environment, for agriculture, for food safety and veterinary affairs, for energy and two federal research institutions: ETH Zurich & WSL. These nine organizations constitute the permanent network NCCS	Swiss Federal Institute of Aquatic Science and Technology (Eawag)
No. of projects	5	7	10-14
Assigned work percentage to leadership	60% (two positions of each 30%), later 100% (distributed among 3 positions)	160-180% (distributed among two positions)	100-150% (distributed among three positions)
Background of program leaders (gender, position, discipline(s), work experience outside of academia (if yes: field), motivation)	• Co-lead 1: male, group leader, Land Change Science and Macroecology, motivated to lead inter- and transdisciplinary teams, enjoys bringing different perspectives together and reflecting upon the how-to of leadership in such contexts • Co-lead 2: female, Office of the Director member, Environmental Sciences, Knowledge and Technology Transfer, work experience outside academia (development cooperation), motivated by the opportunity to open up new topics, to embrace complexity with creative methods and to facilitate dialogue in large settings	• Main lead: male, deputy group leader/head of NCCS program, Atmospheric Physics and Climate Modeling, work experience outside academia (public administration), motivated by looking at climate impacts from several angles, the inter- and transdisciplinary (leadership) challenges involved, the innovative character and potential of the program and the elaboration of actionable products in the form of climate services • Deputy lead: female, communication and project management specialist, Earth Sciences and communication/management, work experience outside academia (public administration), motivated by networking with different actors, connecting different knowledge areas (thinking broadly), bringing climate related solutions forward, coordinating communication activities and supporting management with efficient tools	• Main lead: female, group leader, Geoecology and Inter- and Transdisciplinary Studies, work experience outside academia (development cooperation), motivated to work with different people across hierarchies, and to bring different perspectives together in terms of targeted synthesis outputs, enjoys doing work at the interface between different disciplines as well as between science, policy, and practice and reflecting upon the leadership challenges involved • Deputy lead: male, group leader and directorate member, Environmental Engineering and Solid Waste Management, work experience outside academia (development cooperation), motivated to work on the topic of sustainable urban water management from different angles, creating the bigger picture and deriving overarching lessons learned
Steering Committee	Yes (annual meetings)	Yes (bi-annual meetings)	No
No. of collaborators	~ 20-25 (core team) ~ 90-100 (core team plus partners from science, policy and practice)	~ 20-25 (core team) ~100 (core team plus partners from science, policy and practice)	~6 (synthesis team) ~20-25 (core team) ~80 (core team plus partners from science, policy and practice)

Interactions between program and project leaders	• Bilateral project meetings (4 times per year, 1.5-2 hours) • Program meetings (3 times per year, half day) • Annual program meeting with guests (full day)	• Regular meetings between program lead and project leaders (every two months, 1.5 hours) • Annual program meeting (full day)	• Monthly meetings (2 hours) • Interdisciplinary workshops (~ 3 times per year, 2 hours) • One retreat per year (1.5 days)
Disciplinary background of program participants	Biodiversity, Cryospheric Sciences, Ecology, Forestry, Hydrology and Environmental Psychology	Medicine, Veterinary Medicine, Ecology, Agronomy, Economy, Sociology, Forestry, Hydrology, Energy, Climatology, Geography	Environmental Engineering, Environmental Health Psychology, Decision Analysis, Human Geography, Innovation and Transition Studies, Inter- and Transdisciplinary Studies, Political Science, Process Engineering, Urban Planning
Sectors involved	Agriculture, Animal Health, Ecology, Environment, Forestry, Hydrology	Health, Animal Health, Environment, Hydrology, Ecology, Energy, Civil Protection	Urban Water Management, Art & Design, Technology Companies, Development & Cooperation
Duration	2021-2025	2022-2026	2016-2018 (Phase I), 2019-2022 (Phase II)
Funding Source	WSL internal funds	Joint funding by involved Swiss federal offices and federal research institutions	Eawag Discretionary Funds, Swiss National Science Foundation, Bill & Melinda Gates Foundation, Swiss Federal Office of Environment, Swiss Agency for Development and Cooperation, in-kind contributions of involved researchers
Application & Selection Process	• WSL internal call developed bottom-up in a co-creation process involving WSL researchers to delineate system boundaries; projects were assessed by external evaluation board; final selection by the steering committee • Selection criteria included: 1) Clear focus on extreme impacts on environment and society, 2) relevance to stakeholders, 3) inter- and transdisciplinarity, 4) knowledge integration activities within and beyond project boundaries	• Two-stage process of procurement. First, a NCCS-internal call was run to mandate research groups within the NCCS. Second, an open call under WTO-requirements was published with different lots for different projects to be funded. The consortia per project/lot were selected by project-specific external evaluation boards • Selection criteria included (among others): 1) accordance with the objectives of the project, program and NCCS, 2) innovation potential, 3) expected impact on climate services landscape, 4) plausibility of the work plan and suitability to reach the project goals, 5) experiences in inter- and transdisciplinary cooperation and experience in the climate service sector. The criteria were assessed based on the submitted concept and reference form as well as virtual presentations. The price of the offer was also evaluated and weighted with 20% in total	• No call; Wings emerged bottom-up by an interdisciplinary group of senior researchers at Eawag, who submitted several interlinked research proposals on sustainable urban water management to the Discretionary Funding Call by the Eawag Directorate. Additional existing projects (funded by other sources, see row above), relevant to the program's topic also became part of Wings • Selection criteria included 1) strategic importance to Eawag 2) potential to strengthen Eawag's capacity for inter- and transdisciplinary research, 3) potential to initiate or strengthen collaborations with external partners, and 4) lack of external funding sources
Website	www.wsl.ch/extremes	www.nccs.admin.ch/impacts	www.eawag.ch/wings

The three programs were selected, because

1) they are all based in Switzerland which made them accessible to be studied in depth due to the geographical location of the authors,
2) they all deal with sustainability issues and aim to integrate perspectives across disciplines but also science, policy and practice,
3) they all represented a valuable source of experiential knowledge on the challenges of leading integration as all co-authors were involved in the program leadership,
4) the leaders of the Extremes and NCCS-Impacts program were very interested in being part of the suggested accompanying research by the lead author and willing to dedicate substantial time to it, and
5) all programs faced similar challenges in terms of integration, but differed slightly in their set-up and how the program came about, which allowed for the exploration of different design options for future ITD programs.

The lead author of this paper was involved in supporting the leadership of the Wings program (2019-2022), while also conducting accompanying research in all three ITD programs over the period of three to four years (2020-2023). The accompanying research consisted of a qualitative research design, triangulating semi-structured interviews, reflection questions, focus groups and participant observation. Being involved in the leadership of the ITD program Wings entailed both opportunities as well as challenges for the lead author. Assuming an integrator role (Defila & Di Giulio, 2018b; Hoffmann, Deutsch, et al., 2022) within Wings allowed the lead author to gain in-depth experiential knowledge about co-leading integration processes instead of just observing others leading such processes or relying on their self-reports. On the other hand, switching from an integrator role to a meta-type research role (ibid) was not straight forward and meant consciously altering her "positionality in relation to the team" (Freeth & Vilsmaier, 2019, p. 58). A critical reflection on on-going processes within Wings and her own leadership role was especially challenging during meetings, workshops, retreats or workload-intense weeks. It was therefore important to create explicit reflective spaces in order to take a step back from the integrator role and to document observations and reflections using a reflection-tool developed for that purpose (Deutsch & Hoffmann, 2021b). The lead and last author applied the tool in several instances, but did not always succeed in documenting their observations and reflections in the "heat of the moment" of daily program workloads. For this reason, the bi-annually scheduled focus groups with the leaders of the other two programs were crucial as complementary reflection spaces. What is more, experiences gained within Wings necessarily influenced the lens through which the lead, penultimate and last author viewed the other two programs. It was therefore key to contrast the experiences from Wings with those of the other ITD program leaders (i.e. Extremes and NCCS-Impacts).

The co-authors of this paper were or are the leaders of the presented programs and met on a regular basis during the biannual focus-group meetings within the frame of the lead author's accompanying

research[11]. All programs were or are run on the basis of a co-leadership structure, which was either designed from the very beginning, or evolved throughout the course of the program. Although the co-leaders of each program closely worked together, one person was officially designated core leader, while the other was designated deputy leader in the case of NCCS-Impacts and Wings. All co-authors met five times for biannual three-hour focus-group meetings between May 2021 and May 2023 to jointly reflect on challenges of leading integration in ITD research programs, sharing empirical insights, lessons learned and exchanging ideas about strategies and concrete actions to address them. Insights gained throughout those focus groups were fed back into their own program leadership practices, in particular by including new integration methods or considering new design principles and/or evaluation criteria in assessing research proposals. In addition to this focus group series, the lead author addressed the research question by conducting *bilateral interviews* with five to eight participants from each program (duration 1.5 hrs) and all program leaders between April 2021 and September 2022 (see interview guideline in the appendix). In addition, she performed *participant observation* by attending program meetings, retreats and events at least three times a year per case study between November 2021 and May 2023. Insights from the interviews and participant observation informed the content and structure of the subsequent *focus group* with the program leaders. Triangulating these qualitative methods throughout the research process proved very beneficial for studying the topic from different angles, mutually informing and complementing each other. In addition, it allowed studying the perspectives of both program leaders and participants, which is in line with our definition of integrative leadership, i.e. as an interplay of creative and supportive contributions from both leaders and participants along the integration process (Mainemelis et al., 2018).

All interviews were recorded with the permission of the interviewees and subsequently transcribed. As both program participants and the respective leaders of these programs were interviewed, it was crucial to ensure anonymity. For this reason, only the lead author, who had conducted the interviews, also analyzed them. However, the findings were validated and enriched by the program leaders as will be explained in the following:

Step 1: The lead author collected and noted challenges and fields of tensions, which were reported by both program participants as well as leaders with respect to leading integration processes in ITD programs from the transcripts, explored them in Nvivo 12 (QSR International) and coded them in Excel.

Step 2: The lead author then triangulated the findings from the interviews with her notes from the focus-group meetings and participant observation to derive overarching themes, i.e. six leadership challenges which represented re-occurring themes related to leading integration across the three different case studies as well as across program leaders and participants.

[11] AMH is the director of the NCCS from which the program NCCS-Impacts originated. She was strongly involved in designing and setting-up the NCCS-Impacts program together with AF, and therefore also became co-author of this paper. The current NCCS-Impacts deputy lead joined at a later point when the accompanying research was already about to be concluded and was therefore not part of this manuscript writing process.

Step 3: The lead author presented these six overarching themes to the program leaders in the focus group in May 2023 and provided empirical evidence (i.e. anonymized quotes from the interviews and observations from attending meetings) for each challenge. The program leaders (and co-authors) concluded that these themes represent core (and often unresolved current) challenges in their daily leadership practice in ITD programs, although they do not necessarily represent an exhaustive list. During this focus-group meeting, the six leaders enriched these themes with practical examples about how these challenges can be potentially addressed in the future or already have been addressed by them in the past.

Step 4: In the subsequent months, the lead author and six leaders jointly wrote the manuscript at hand, thereby iterating and refining the six challenges and the practical strategies further by mirroring it with the existing literature on leadership in ITD programs.

Step 5: The manuscript was sent to the interviewed program participants before being submitted to the journal in order to allow them to check our analysis and conclusions. Two program participants responded, but did not ask for any modifications.

6.3. Results and discussion

"*This area of tension that there are these ideal-typical integrative processes, as described in the literature, but then the bare everyday life, it just looks a bit different. And to endure this balancing act between "what could be theoretically possible" and "what actually happens in practice", is sometimes not so easy."* (Leader)

In the following, we describe six core leadership challenges derived from the empirical material and the hands-on experience of leading ITD programs for several years. While it is possible to distinguish those challenges to a certain extent conceptually, we are well aware that they interrelate and overlap in practice. We first introduce the respective challenge, and then propose concrete coping strategies that proved useful to address the challenge. We structure these strategies according to (1) attitudes, (2) processes, and (3) structures.

6.3.1. Information overload ahead: mastering complexity and ambiguity

ITD programs have become one of academia's responses to address complex societal challenges. In order to fulfill their purpose, it requires a more complex and ambitious research process too (van Kerkhoff, 2014). Therefore, ITD programs are by default overwhelming for all partners (Bruce et al., 2004), but in particular for program leaders. The more complex the ITD initiative, the greater the demands on leadership, and related to that: "the greater the potential impact of effective or ineffective leadership" (Hall et al., 2019, p. 596).

First, content-wise program leaders face an immense information overload due to the large number of disciplinary topics that are in part also new to them. While they can selectively dive into the deep sea of disciplinary and sector-specific knowledge, they do not have to become experts in these areas. By contrast, it is their responsibility to keep the overall program goals and system boundaries in mind and counter potential diverging developments that could cause the program to fall apart (see subsequent subchapters) (Defila et al., 2006, p. 142). This implies that, throughout program implementation, they fluctuate between the bigger picture (program view) and in-depth expertise (project and work-package view) as expressed by one junior participant:

"The program leader is the one who has the bird's eye view…and the group leaders are the ones who have the tunnel vision, the narrowness that's required for the topic..." (Junior Participant)

Program leaders therefore need to be capable of envisioning how the different perspectives involved actually overlap and need to interplay with each other (Gray, 2008). Doing so requires interactional expertise (Collins & Evans, 2007) implying that program leaders need to master the language of the various disciplines involved to a certain degree without necessarily being able to contribute to these disciplines in depth. However, to manage this type of co-creation and not getting lost in sight of this immense challenge, it is imperative for program leaders to keep warding off the feeling of inability to ever grasp the complexity in every detail, as expressed by one program leader:

"Sometimes it feels like an information overkill, to understand all projects and what else is going on ... There are so many big new topics. That is also very stimulating, but sometimes I have the feeling that, "wow, I just want to read something [in my area] again", "have safe ground under my feet again." (Leader)

Working in large-scale ITD initiatives inevitably leaves behind a feeling of imperfection and incompleteness (Black et al., 2023) that can never be fully solved. This is further intensified as ITD programs are not only demanding in terms of handling diverse content, but equally in terms of handling differing social, political, legal and institutional contexts. This was a challenge for the NCCS-Impacts program as leaders and participants were confronted with setting up a program despite very different regulatory frameworks of the involved Federal offices.

Hence, ITD programs need to serve many interests. When a new program is developed within or across institutions, first the funders – in some cases the respective directorate or federal offices – need to be convinced that the program is worth being funded. This tends to lead to the fact that program calls end up making overly ambitious promises, which can be hardly met in practice. These promises include the ambition to find concrete solutions to pressing problems by doing cutting-edge research and conducting participatory processes that finally yield innovative solutions useful not only to science, but to multiple sectors and its respective actors within a short time-frame (often 4-5 years). In the same vein, applicants for projects take up the wording of the call and promise much for little money to win the grant. With

such an ambitious call, the expectations of the funders are immense while participants are overly pressured from the very start. In particular, the achievement of both high scientific and high societal impact might be unrealistic within such limited time-frames (Roux et al., 2010; Ruppert-Winkel et al., 2015). For this reason, expectations have to be necessarily lowered to what is realistically possible under given individual, team, project/program, institutional, financial and societal conditions despite the complexity of the research topics at hand (Deutsch et al., under review).

Leadership strategies related to "mastering complexity and ambiguity":

- **Attitudes:** Be aware of your role as integrator, not disciplinary knowledge carrier. You do not need to understand all disciplinary and sectoral fields in detail, but rather their interfaces and the bigger picture. Being able to do the latter is sought-after expertise in itself.
- **Processes:** Do not be overambitious, but treat integration as a step-by-step process together with a dynamically evolving team and a high potential for learning. Ask program participants to synthesize and translate their current results via pitch talks or two-pagers, and use methods to render complexity comprehensible (i.e., visualizations, story-telling techniques or system-methods, e.g. Theory of Change) (Deutsch et al., 2021; Hinnen & Hinnen, 2017).
- **Structures:** Organize structural support, be it through setting up a co-leadership with complementary expertise, an inter- or transdisciplinarily composed evaluation or advisory board, or by joining a community of practice with other program leaders. The latter can help to build up ambiguity and complexity tolerance.

6.3.2. Pulling the ship forward: advancing decision-making with lateral leadership

ITD programs usually involve a large number of participants affiliated with different organizations. Accordingly, they are used to different leadership cultures, decision-making processes and hierarchical structures. Even within a single organization, participants are embedded in different departments and their respective cultures, and are accountable to different superiors (e.g., PhDs, PostDocs, tenured scientists, department heads). An ITD program typically disrupts this established order as it aims for collaboration, decision-making and enabling resource flows across the common hierarchical structures (Crosby & Bryson, 2010). Achieving this is a leadership challenge in itself given that tasks from the line management in the respective department or organization always 'come first':

"We don't have much formal authority to issue directives. In the federal administration, a lot of things are done via goals and line management. So how do we succeed in people treating our issues as a priority despite not being the primary focus of their respective lines?" (Leader)

As the classic leader-follower-model becomes obsolete in complex ITD programs, leadership is "about understanding and influencing systems interactions" (Will, 2016, p. 274). This makes lateral leadership necessary, as program leaders are confronted with the challenge of leading across hierarchies, while not

necessarily having a strong formal hierarchical power position within the program's 'ecosystem' (Kühl, 2017; Provan & Kenis, 2008). In the most extreme case, program leaders need to lead program participants who are not only hierarchically ranked above them, but are also their direct superiors, which can lead to problematic power dynamics if the latter do not manage to separate these two roles in practice.

Such hierarchical constellations, but also the need to consult and discuss with a high number of program participants on a regular and iterative basis, bear the risk of getting stuck and causing frustration since consensus is neither easily achievable nor always possible (Black et al., 2023) as expressed by one leader:

"*So this democratic, participatory process is good, but it is of course much more time-, nerves- and energy-consuming. It needs a lot of iterative loops, I think…it is a disadvantage in the sense that sometimes you simply have these experiences of frustration much more often, [this feeling] that you don't progress*." (Leader)

Many program participants want provide opinions and suggestions concerning the program course. Yet, time-wise leaders sometimes need to take top-down decisions too, in order to push the program and respective integration process forward. Gray (2008, p. 5) calls this 'judgment calls', i.e. the leaders capability to "make discriminatory decisions about numerous issues" including for instance which ideas are most promising, what next steps are needed and being realistic in terms of advancing integration. This can sometimes lead to discontent, as expressed by one leader:

"As soon as you do something that hasn't already been agreed on by everyone because of time constraints or something, it blows up in your face" (Leader)

One program participant compared the practice of leading an ITD program with the challenge of 'herding cats' i.e. the futile attempt of wanting to control the uncontrollable:

"Everyone's trying to go in their own direction and you have to bring them all together." (Junior Participant)

While ITD programs and integration processes can certainly never be under full control, integrative capabilities (Salazar et al., 2019) are key to obtain and maintain order in such a complex setting at least to a certain extent. These include high levels of reflexivity (Guimarães et al., 2019; Salazar et al., 2019), contributory and interactional expertise (Bammer et al., 2020; Collins & Evans, 2007), complexity thinking (Uhl-Bien & Arena, 2017) as well as specific attitudes such as openness, curiosity, sociability and a modest positionality (Augsburg, 2014; Fam et al., 2017). Next to developing integration expertise (Hoffmann, Deutsch, et al., 2022), this also includes assuming a neutral and benevolent position within the program, i.e. not having one's own project within the program, which competes with the other projects about academic interests and purpose, and the ability to develop good relationships with the

respective program participants. The latter also includes considering that different participants have different preferences to contribute or express themselves (e.g. oral vs. written feedback).

Leadership strategies related to "advancing decision-making with lateral leadership":

- **Attitudes:** Be aware of the necessity of lateral leadership and gain respect as lateral leader by assuming a neutral and benevolent role in the program. Do not expect that you will be able to always satisfy everyone. Reflect regularly on your achievements, especially the allegedly smaller ones.
- **Processes:** Balance top-down and bottom-up leadership, i.e. show presence and act quickly when concerns arise. At the same time, always align concerns, tasks and questions with agreed program goals. Expand your sphere of influence by gaining insider-knowledge (e.g., how decisions are made in different departments/organizations), expanding your network and establishing good relationships with program participants. For avoiding a stalemate, fall back onto already agreed program goals as well as governance structures.
- **Structures:** Get an official role in your organization's organigram assigned to gain visibility and legitimacy. Establish a governance structure of the program that is approved by all program participants, but also by their superiors as well as, by a steering committee (if existent). The governance structure should clearly reveal the process of how decisions are made within the program.

6.3.3. Non-integration as default: ensuring responsibility and accountability

Integrating activities and results from different projects into a larger framework and developing joint synthesis products is a key purpose of ITD programs and therefore also a key indicator to assess their success. Doing so inevitably requires joint efforts of large and diverse teams with complementary expertise. Yet in academia, individual members are encouraged to foster first and foremost their own particular disciplinary research agenda. Processes necessary for knowledge integration are therefore often perceived as an unnecessary and unwanted distraction. Given this unfavorable incentive structure, it is often uncertain whether participants in ITD programs are actually willing to assume responsibility for integration processes at the program level and feel accountable towards the overall program goals as described by one senior participant:

"*You can then hide a bit in this irresponsibility, you can pass on the responsibility to someone else. Because X didn't moderate it well, right? ... And I think that's perhaps a structural problem, also from a perception point of view: I'm not held accountable if things don't work out so well [within the program]. Or I think I won't be held accountable.... So maybe I still will at some point.... (laughs)*" (Senior Participant)

The fact that usually contributes to non-integration is that usually early career researchers perform most of the work within a program as senior participants tend to be very busy and are involved in multiple projects:

Interviewer: Did the integration method on the program level yield any new impulses for your individual project?

Interviewee: Yes, additional tasks that I will offload to my PostDoc now. (Senior Participant)

However, early career researchers usually leave after two to four years as they often do not have the prospect of staying at the institution until the program and its final outputs are finished due to the common practice of rather short fixed-term contracts in academia. On top, early career scientists are sometimes discouraged by their supervisors from investing too much time in ITD activities as it is considered to be diametrically opposed to career development in academia.

As integration processes are quite demanding in terms of cognitive and social-emotional challenges (see subchapters 6.3.1. and 6.3.2.), the lack of felt responsibility and accountability may also stem from the program participants' difficulties to deal with these challenges as one leader explains:

"*For me, integration is a lot. It's back-breaking work too, very time-consuming. A process. A bit of Sisyphean work. You can't just schedule it somewhere and do it and then it's done, but you have to keep working at it and if you don't stay on the ball, then it disintegrates again or recedes into the background. Because 'the other' is so much more comfortable, the non-integrative, the disciplinary. Just do your thing and do what you've always done*". (Leader)

Building on the previous chapter (6.3.2.), a mere top-down leadership approach for fostering responsibility and accountability does not work in such contexts and is not even desirable as integration requires creative contributions emerging bottom-up from the participants too (Uhl-Bien et al., 2007). By contrast, it necessitates a good balance of offering support and guidance while still demanding their contributions to the overall integration process and synthesis products as one senior participant explains:

"*I think [the program leaders] are forcing us again and again to take an integrative approach, to think or even to discuss a new method together. If they didn't keep up that drive and also think about how to make these retreats interactive and try to get the most out of the limited time we have, there would be less integration"* (Senior Participant)

The experience from the three programs shows that when leadership comes with a positive, supportive and encouraging attitude yet critical stance where needed, participants feel respected and are more likely to engage and showcase the progress they have made towards integration. In light of our findings and the current conditions in place (Deutsch et al., under review), we agree with Boone et al. (2020, p. 1725), that program leaders "must be [currently] more persuasive than other leaders to convince researchers to follow the unsettled and novel pathways of ITD research."

Leadership strategies related to "ensuring responsibility and accountability":

- **Attitudes:** Acknowledge the difficult incentive structures in place and do not judge immediately if people have a hard time doing integrative work. Support them as much as possible during integration processes by providing them with integration methods and training. You can't do the integrative work for them, but you can assist them in their efforts.
- **Processes:** Lead proactively and keep a continuous focus on integration and final synthesis products from the very beginning, i.e. hold regular face-to-face meetings and vary interaction formats (bilateral or program meetings, workshops, etc.) to ensure that integration remains on top of people's agenda. Clearly communicate the envisioned steps and timeline for working on integration and creating synthesis products. Do not underestimate the importance of social events (e.g. joint drinks/dinners, excursions, retreats) for building ownership and responsibility towards the program.
- **Structures:** Define and assign responsibilities and obtain commitment from all participants to engage in integrative processes and generate integrated outputs, i.e. put on record that individual projects are responsible for integration at the project level (i.e. integrating their stakeholders), but also need to contribute to the overall synthesis. Ask for and retain funds for synthesis activities in order to be able to flexibly use them for filling potential synthesis gaps and needs. Draw lessons learned during and after the program and share them for future ITD programs.

6.3.4. Keeping the program manageable: setting boundaries

When dealing with broad complex societal problems, program leaders experience the challenge to define the program's system boundaries thematically and socially. Regarding thematic boundaries, there is the risk of trying to incorporate themes exhaustively resulting in a program that wants all and nothing at once, as many aspects and sectors are strongly interlinked due to the complexity of the topics at hand. Strongly related to the thematic boundaries is the question of social boundaries. In all three ITD programs recurring discussions emerged about 'inclusion' and 'exclusion': "Who is invited to participate in the program and who is not? What criteria are used to define and select program participants and who defines these criteria? This defines who gets empowered by the program, and, the other side of the same coin, who gets marginalised?" (Elzinga, 2008, p. 357).

Based on our experience, we argue that setting the program's social boundaries needs consideration of the purpose, form and time of inclusion (or exclusion) as well as the issue at hand rather than 'the more inclusive (or exclusive), the better' (Krütli et al., 2010) approach. Adopting this functional-dynamic approach (ibid) to setting social boundaries might sometimes entail temporarily excluding some

participants at a given point in time (and (re)include them at a later point) to sustain the integrative process and allow new ideas to flourish (Hoffmann, 2024), as noted by one program leader:

"My experience is that things move forward when you continue with a smaller group and (when you) do not always have the aspiration to do everything with everybody. (…) And then there is this area of tension between including new people in the program, for example, the junior members, because they are the ones who actually do most of the work." (Leader)

As noted by this program leader, the issue of inclusion and exclusion involved also a discussion on the extent and the form of including early career researchers in the program (Scientific Assistants, PhDs, PostDocs). Experience within Wings showed that deliberately including them in the program's thematic and strategic discussions proved beneficial, as early-career researchers provided not only empirical insights on real-world examples of alternative urban water systems, but also challenged the status quo: They pointed to 'what is desirable', while senior researchers rather highlighted 'what is feasible' – two complementary perspectives which helped to enrich the program's discussion on sustainability transformation in the urban water sector substantially (Deutsch et al., 2021). Ensuring this social integration of early-career and senior participants is perceived as one of the key leadership tasks as explained by one senior participant:

"To me, it doesn't really matter whether you're a professor, a Nobel Prize winner, or a Bachelor student. If you have an idea and you have something to support it, your opinion matters as much as the other ones. I think communicating this makes integration a bit easier and more feasible because then people don't feel like they cannot talk, they cannot express their results, feeling, opinion, whatsoever. " (Senior Participant)

Therefore, program leaders have a powerful role in shaping social integration or inclusion processes, especially in terms of balancing power differences (Kok et al., 2021). Establishing boundaries might appear counterintuitive to ITD endeavors, but is critical for keeping the program manageable both in terms of content as well as participants.

Leadership strategies related to "setting boundaries":

- **Attitudes:** Be aware that integrative leadership does not mean including everyone all the time. Take a step back and decide together with the project team task by task who needs to be strategically included as well as (temporarily) excluded to move integrative processes forward; then adapt and vary formal (e.g. retreats, workshops, meetings) and informal interaction formats (e.g., coffee and lunch breaks) accordingly and alternate group compositions.
- **Processes:** Create protected niches for early career researchers or other sub-groups (e.g. a proper workshop or retreat with early career researchers only or cross-cutting panels by participants from different projects that focus on specific aspects of integration), so that new

ideas have the chance to flourish and advance faster in smaller groups. Acknowledge and use the complementary expertise of early career and senior researchers.

- **Structures:** Define the program's thematic and social boundaries in concrete and explicit terms, e.g. organize scoping meetings prior to publishing the call to set the program boundaries consciously. What and who is part of the program, and what and who is deliberately excluded? Collect the commitment of all participants and the program board in a written document and make it available to all.

6.3.5. Counteracting chance: selecting suitable projects

Program leaders have the task to make integration happen across the different projects involved. Yet, they are sometimes excluded from the project selection process. This has both advantages and disadvantages: Being excluded from the selection process allows program leaders to assume a more neutral role vis-a-vis the program participants and often colleagues. As a drawback, they have to accept suboptimal decisions by the proposal evaluation board, such as when the selected projects do not fit well together as expressed by one program leader:

"*X and I, we were not part of the evaluation board and hence couldn't decide. […] It is up to us to see how everything fits together. As the boundaries were already set through the call, we could accomplish this more or less. But what remains a challenge is that by this procedure we couldn't control who receives the funding. For instance, whether these people are willing to collaborate is out of our control.*" (Leader)

In a similar vein, a junior participant stated from another program context where the involved projects did not necessarily fit together in terms of content, and participants:

"[*The program] is confronted with a lot of challenges…, which I would summarize as '40 people from 20 disciplines with 50 opinions and only a few common interests as well as an unknown number of hidden conflicts come together and are supposed to jointly advance a program'".* (Junior Participant)

When selected projects and the involved individuals do not fit well together at the program level, program leaders need to be creative on how to fill the gaps and how to integrate the pieces, while the temporary evaluation board is dissolved again and can't be held accountable for its decisions anymore. In the case of ITD programs the evaluation board usually comprises representatives from different disciplines as well as actors from practice coming from both the country of the host institution and abroad. Board members have to jointly evaluate the proposals in a relatively short timeframe without having met before. An oral and written briefing helps to align the evaluation team under a common vision and strategy and to familiarize the panel members with the background and intricacies of the call. However, it does not guarantee that - despite these efforts - 'traditional' criteria (e.g. scientific

innovation) are given more attention than others (e.g. potential for creating practical knowledge and tools for societal actors), although the evaluation guideline and criteria are pre-defined along both lines.

The experience from all three programs shows that ITD aspects, products and overall program synthesis tend to be given less priority by the applicants as well as the evaluators. Hence, the management of the selection process by the program leader is critically important: it requires "informed staff giving clear guidance to panels on how to evaluate interdisciplinary initiatives and appointing a panel chair with a good understanding of what is required and a strong enough control over the process to ensure that the guidance is followed" (Lyall et al., 2011, p. 4). With the program leader being excluded from the selection process, the question is who is sufficiently skilled and experienced in ITD and can ensure that ITD criteria are taken seriously (Bruce et al., 2004; McLeish & Strang, 2016) and not "sidelined in favor of conventional disciplinary criteria" (Lyall et al., 2011, p. 4).

How this guidance should look like in concrete terms, and against what criteria proposals should be evaluated often needs to be defined already when publishing a call. However, this is done without knowing to what extent the scope of the call and its objectives match the ability, interest, resources and willingness of potential applicants. In the case of Extremes, which is an institution-internal research program, the potential future applicants co-created the call via a workshop series. This had the advantages that (a) the call was in line with the available resources of future applicants, (b) a common system understanding was developed already prior to the program start, and (c) those with no interest in ITD activities had the opportunity to withdraw early on. At the same time, having participated in the framing process, but then not having been selected for the program can cause frustration among the respective individuals. Verwoerd et al. (2020) found benefits in combining the facilitator's and evaluator's role, and including participants in a formative evaluation approach to achieve a meaningful assessment of the projects' societal impacts. Similarly, we believe that there is added value in both including the future program leaders in the selection process and considering future applicants' perspectives when designing the call as this phase lays the foundation for later integration work (König et al., 2015).

<u>Leadership strategies related to "selecting suitable projects":</u>

- **Attitudes:** Be conscious and transparent about the advantages and disadvantages of being included or excluded from the selection process. This holds true about how the process as such should be set-up, as different set-ups provide both challenges and opportunities. In any case, the decision by the evaluation board will have a great impact on your work and consequences for the integration process and integrative leadership.
- **Processes:** Allow enough time for briefing the evaluation board in-depth, but also make sure that scientific excellence criteria do not rule out criteria such as the potential for real integration and societal impact during the evaluation process as you will later be responsible

for moving integration forward. Ideally, the evaluation board covers a broad range of disciplines, and also comprises inter- and transdisciplinary competences.

- **Structures:** Engage the evaluation board early in the procurement process and ask the members to assume responsibility on a longer term, e.g., as a sounding board member. In this way, they are held accountable for their choice, which might influence their decision-making process. Make a clearly outlined integration concept a requirement for proposal submission already in the call, and build in specific questions for assessing the envisioned integration in the evaluators' guidelines (Belcher et al., 2015; Pohl et al., 2011; Strang & McLeish, 2015). Require projects to dedicate budget (e.g. 15-20%) for ITD activities in order to be eligible.

6.3.6. What others think I do: dealing with misconceptions

Program leaders are often confronted with very diverse and sometimes diverging expectations of what their role as leaders of integration actually encompasses. As their position involves a range of different roles, they not only need to attend to diverging expectations and manage the inherent tensions, but also have to balance and combine them consciously (Hoffmann, Deutsch, et al., 2022). Often, these role(s) and related leadership tasks are not explicitly defined and underestimated in their complexity. Leading an ITD program is often depicted as mainly operational business, where program leaders are assigned a more executive and passive role than is actually required to advance integration, as reported by one program leader and one junior participant:

"*By statute and rules of procedure, I could withdraw fully into the operational business… but it just doesn't work that way… We are the drivers, a bit of the bracket that holds it together, sometimes also a bit of the unpleasant drivers that just annoy you. We have to play a very active role.*" (Leader)

"*I think the problem is, if you have a meeting, a couple of hours or something, I'm sure everyone's going to throw in some ideas, but these ideas don't necessarily all make sense together. I think someone has to sit down and really think everything through and try to make a coherent strategy rather than only brainstorming among the group. I think it is always nice to generate ideas, but it doesn't necessarily produce something which is feasible [for moving forward].*" (Junior Participant)

An active role is needed beyond setting up and kick-starting the program, as integration needs to be continuously encouraged, guided and sustained over time to attain integrated outputs (Andrews et al., 2024; Hoffmann, Deutsch, et al., 2022; Hollaender et al., 2008; Ruppert-Winkel et al., 2015) as expressed by one leader:

"I have now received a new work package and then I was told "the program is now initiated, it is running, now you have free capacities for other tasks". This [lack of] understanding I also find a

challenge; understanding that the program becomes better when it is [proactively] led instead of just assuming that something will hopefully come out of it at the end." (Leader)

This finding resonates with Hollaender et al. (2008, p. 387), who argue that a "laissez-faire type of leadership, which hopes that the different parts of the work of transdisciplinary teams will grow together organically has not proven successful". It is therefore key that program leaders have explicit resources at their disposal, i.e. time and money, for pushing integration forward as well as being able to reflect upon it (Roschewitz & Björnsen Gurung, 2021). In the case of Wings this meant both leading integration, and also studying it (Hoffmann et al., 2017a).

This lack of understanding is also reflected in the common performance indicator databases, where researchers have to assign their work to pre-defined and standardized tasks used for collecting and assessing researchers' annual academic outputs. The high amount of bilateral, group or program-wide meetings, workshops and creative processes for advancing integration and creating 'non-traditional' outputs beyond publications, are hardly accounted for in such databases, causing frustration as one leader reports:

"I had the feeling that, "wow, I've done so much in the last year, so incredibly much" and then I went into the indicator database, and I realized that I can't fill in almost anything; what I'm doing doesn't fit into the database. And I find that a bit unsatisfactory." (Leader)

Moreover, program leaders are often miscategorized as coordinators, facilitators or administrators of integration. While coordination, facilitation and administration are essential parts of their role, such a conceptualization reduces their intellectual contributions to scholarship to a mere "supportive service role" rather than a very essential "creative science role"(Bammer et al., 2020; Hendren & Ku, 2019; Hoffmann, Deutsch, et al., 2022). Referring to this sort of miscategorization, several program leaders and participants indicated that they perceive it even as a risk to take over such a leadership role because one might be no longer be regarded a "scientific expert", but rather an "academic lightweight", producing nothing of substance (Oliver & Boaz, 2019) as their cognitive-intellectual contributions are largely invisible and unrecognized (Bammer et al., 2020).

Leadership strategies related to "dealing with misconceptions":

- **Attitudes:** Be aware that leading an ITD program is not an operational side-task, but a proactive and creative core task. Therefore, allocate sufficient time, as it demands immense resources not only at the beginning for setting-up and kick-starting the program but throughout the whole program duration.
- **Processes:** Make both your supportive service as well as creative science contributions visible. Make explicit what tasks this leadership role entails (see Figure 4 in subchapter 6.4.) to program participants, but above all towards your superior(s). Establish 'updates from the

program lead' as a firm agenda item during meetings with the project teams to report on activities and achievements.

- **Structures:** Propose a revision of the current performance indicator database by providing a list of activities, achievements, process-indicators, etc. to the responsible department. Demand from/suggest to your superior that leading an ITD program is - for your academic career - considered an equally important and scientific qualification step as contributing to a disciplinary community.

6.4. Overall implications for integrative leadership in ITD programs

As subchapters 6.3.1. to 6.3.6. have shown, integrative leadership comprises a broad portfolio of tasks and responsibilities in different areas. Figure 4 (further below) provides an overview of this portfolio and specifies which tasks are rather supportive and which ones are creative contributions in line with our definition of integrative leadership (Mainemelis et al., 2018). This conceptual distinction is key, as different areas of the leadership portfolio also require different expertise, experiences and skill-sets. Studies on other ITD research programs or larger ITD projects (Bruce et al., 2004; Defila et al., 2006; Hoffmann et al., 2017a; König et al., 2013; Roux et al., 2010) similarly concluded that the role of the program leader(s) is a crucial and complementary one to those of the project or work-package leaders, and requires assuming a wide range of tasks which matches our conceptualization of integrative leadership as a broad portfolio of tasks, roles and expertise (Figure 4). Tasks located in the realm of supportive contributions (left side) for instance require, above all, good communication, coordination, moderation and methodological skills. The more one moves into the realm of creative contributions (right side), the more integration expertise becomes necessary to fulfill these tasks. However, skill-sets necessary for supportive contributions are of course equally relevant to creative contributions (e.g. good communication skills to be able to integrate). As it is unlikely that one individual can be outstanding in all those areas (Krainer & Lerchster, 2015), co-leadership with complementary expertise, experience and skill-sets becomes a fruitful way forward.

We suggest considering these areas as 'modular', meaning that depending on the program phase, certain areas might temporarily require more attention and resources than others. However, all areas are essential, hence need to be covered to be able to realize integration in ITD programs and accordingly require sufficient time and resources. With limited time, the focus often lies merely on coordination and communication, leaving aside the application of integrative methods or the generation of final synthesis products. In light of the empirical material, our experiences and the time resources that were at our disposal (see Table 7, subchapter 6.2), we recommend to assign for these tasks at least a 100%, and up to 300% FTEs (full-time equivalent) to ITD programs of the size of Wings, Extremes, or NCCS-Impacts. The exact percentage depends on the program contexts, as some programs might already be set up from the very beginning with a higher potential for synthesis than others.

Figure 4: Portfolio of tasks, responsibilities and contributions of integrative leadership in ITD programs (own elaboration)

6.5. Conclusion

ITD programs and their respective leaders need to serve many masters. The metaphor of 'herding cats' is certainly apt in these contexts, given the complexity, ambiguities and centrifugal forces program leaders need to deal with. Hence, courage, strong nerves, intrinsic motivation and integration expertise are a prerequisite to lead such programs. As ITD programs are large structures with a highly dynamic life of their own, many things - challenges as well as new opportunities - cannot be foreseen at the onset of their implementation (Roux et al., 2010; Ruppert-Winkel et al., 2015). The more ITD aspects are built into a program, the more flexibility and agility is required from both leaders and participants, but also in terms of time and funding.

We identified six core leadership challenges, which we encountered when designing, setting-up, and implementing three ITD programs in Switzerland, and presented strategies which have proven to be beneficial for the program leaders in dealing with them. These strategies are meant as suggestions or options, but neither as recipes nor panaceas as program contexts can strongly differ. Therefore, each 'integration concept' and related leadership approach will be to a certain extent 'unique' (Hall et al., 2019). In addition to these six challenges, other program-specific challenges can be anticipated. However, despite the differing contexts of Extremes, NCCS-Impacts and Wings, we were still able to identify overarching challenges and respective strategies common to all programs. We therefore think that our results yield important insights for leaders and funders of other research programs or larger ITD projects (e.g. at EU/international level), which are in line with the research programs and networks characterized by Defila et al. (2006, pp. 16-17) and Schneider, Buser, et al. (2019, p. 1), i.e. ITD research programs which pursue (1) inter- and transdisciplinary integration for (2) addressing a complex societally relevant challenge and aim for (3) a joint synthesis at the program level and (4) the re-integration of results into societal and scientific practices (ibid). Such ITD programs, which aim to achieve scientific and societal impacts at the same time are necessarily characterized by high heterogeneity due to numerous participants (multiple disciplines and stakeholders), multiple projects or work-packages, and (more or less related) research questions for addressing the overarching topic. Therefore, we believe that program leaders in the described contexts are necessarily confronted with the same, or at least similar, challenges, such as how to ensure that program participants feel responsible for contributing to integration across their individual work-packages or projects and how joint synthesis at the program level can best be attained (see again 6.3.3.). Integration can take different forms depending on the specific purpose, scale and scope of such programs (Hoffmann, Deutsch, et al., 2022; Klein, 2008) and does not necessarily imply 'consensus' (Pohl et al., 2021). Moreover, integration cannot always be pursued across all projects or work packages as not all perspectives can be reconciled, particularly at a certain point in time (Harvey et al., 2018) (see again 6.3.5.)

One limitation of our study is certainly that all ITD programs are located in Switzerland – a country where research is usually financed at an above-average level compared to other countries. However, we

believe that this is nonetheless an especially interesting aspect as it shows that a greater availability of funding does not necessarily alleviate all challenges. In addition, it provides an entry point for future research since leadership in ITD programs can be compared across different contexts and countries. To conclude, we want to emphasize that the importance of integrative leadership in academia in general (Cohen & Cohen, 2018) and in ITD research programs in particular (Defila et al., 2006; Gray, 2008; Hoffmann et al., 2017a), tends to be underestimated when designing and setting-up ITD research programs and respective leadership resources. This goes along with an underestimation of the kind of roles, responsibilities and tasks integrative leadership involves, but also the workload it implies to fully exploit the collaborative and integrative potential of ITD programs. While distributing roles, responsibilities and tasks for integration is key in such programs, the overall responsibility to realize that potential must reside with the program leaders (Hollaender et al., 2008). Integrative leadership can never be fully delegated, but always needs to be proactively assumed and wholeheartedly supported by program leaders to ensure that ITD programs live up to their collaborative and integrative ambition – just like herding cats.

7. Leading inter- and transdisciplinary research: Lessons from applying theories of change to a strategic research program (article 3)

Status and journal: Published in *Environmental Science and Policy* (Vol. 120, June 2021)

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Keywords: Interdisciplinary, Transdisciplinary, Theory of change, Leadership, Urban water management, Research programs

Abstract: Theory of Change (ToC) has been promoted as a useful tool in sustainability research for visioning, planning, communication, monitoring, evaluation and learning. It involves a mapping of steps towards a desired long-term goal supplemented with continuous reflection on how and why change is expected to happen in a particular context. However, there is limited reported experience with the development and application of ToCs in inter- and transdisciplinary research contexts. While some previous publications have focused on ex-post application, there has been little discussion about the process of developing and using ToCs in strategic planning and monitoring in large inter- and transdisciplinary research programs. This article reports challenges and lessons learned from the experience of developing and using ToCs in the inter- and transdisciplinary research program Wings (Water and sanitation innovations for non-grid solutions). Challenges include (1) managing time constraints, (2) balancing between concrete and abstract discussions, (3) ensuring diversity in group composition, (4) fluctuating between reservations and appreciation, and (5) fulfilling both service and science roles while leading the ToC process. The experience highlights the importance of alternating formal and informal interaction formats throughout the process, ensuring heterogeneous group formation, involving early career scientists, being responsive to emergent needs and making the added value of developing and using ToCs explicit and tangible for all participants. Although these lessons are mainly derived from developing ToCs within the interdisciplinary program team, they can support other programs in both their inter- and transdisciplinary research endeavors.

7.1. Introduction

A range of new methods (Bergmann et al., 2012; Defila & Di Giulio, 2018a, 2018b; Hoffmann et al., 2017b) and tools (Bammer, 2015; Eigenbrode et al., 2007; Hirsch Hadorn, 2002; Network for Transdisciplinary Research, 2020; Pohl & Wuelser, 2019) has been developed in recent years to support research teams conducting interdisciplinary research (IDR) and transdisciplinary research (TDR). These tools address various aspects of IDR and TDR, including communication, collaboration and integration (O'Rourke, 2017). However, theoretical advances have not always been supported with practical experience and empirical insights. There is a need to test these methods and tools and deliver lessons

learned and adaptations back to the research community. Future users need clear guidance on the methods' and tools' key functions, be aware of the challenges they might face in applying such methods and tools, and the strategies they might use to deal with those challenges. There is also a need for practical insights into how communication, collaboration and integration can be incentivized and strengthened in IDR and TDR.

One tool which has been more recently promoted for inter- and transdisciplinary sustainability research is 'Theory of Change' (ToC) (Belcher et al., 2020; Oberlack et al., 2019; Posner & Cvitanovic, 2019; Schneider, Giger, et al., 2019; Schneidewind & Rehm, 2019). A ToC maps out a change process in a particular context and is used as a "guiding framework for all stages of thinking, action and sense-making" when a project or a program intervenes in processes of social change (van Es et al., 2015, p. 12). It can be defined as both a process and a product (Vogel, 2012b, p. 4). Developing a ToC is an inherently dialogic and reflective process (Vogel, 2012b), which documents the hypotheses and assumptions of researchers and actors (Pohl & Hadorn, 2008) from policy and practice about the key mechanisms and conditions for creating change in a specific context while also describing the causal relationships between project/program interventions and intended outcomes. The ToC as a product is a narrative and visual model (usually represented as a flow chart diagram) that illustrates the main activities, actors and results, as well as the assumptions underlying the change process in the short, medium and long term (Belcher et al., 2020; Mayne, 2015).

For several decades, ToC has been an integral part of community and international development projects and has evolved out of two key streams: evaluation theory and social change theory (Vogel, 2012b). In the field of evaluation theory – in particular program theory – growing dissatisfaction with standard evaluation methods that fell short of assessing the how and the why of complex community projects' successes or failures (Birckmayer & Weiss, 2000; Weiss, 1995) led to the emergence of theory-based evaluation in the 1990s. ToCs have also been influenced by social change theory in the development context. Since the 1970s, when the dominant development paradigm was increasingly challenged due to unsustainable project results, development practitioners and scholars have given more attention to the assumptions underpinning interventions (James, 2011; Stein & Valters, 2012) and started to explore tools in order to "improve development policy and practice" (Valters, 2014, p. 2). As Vogel (2012b, p. 3) notes, "a wide range of development organizations, from grass-roots initiatives in developing countries to donor agencies, have found it an accessible and useful approach" and apply it for planning, evaluation and communication purposes in their projects (Gertler et al., 2016).

A ToC can serve multiple purposes in research, including visioning (Belcher et al., 2017; Oberlack et al., 2019; Weiss, 1995), planning (Belcher et al., 2019; Mayne, 2015), communication, monitoring, and outcome evaluation (Belcher et al., 2020; Douthwaite et al., 2003; van Drooge & Spaapen, 2017), as well as reflection and learning (Halimanjaya et al., 2018; Posner & Cvitanovic, 2019; Ramirez & Belcher, 2018). While these key functions have been frequently discussed in theoretical terms, the

practical aspects of developing and using ToC in large IDR and TDR programs have received less attention. Moreover, there is growing literature on the ex-post development of ToCs used for outcome evaluation, but there is little documented experience on how ToCs are used ex-ante as a strategic planning and monitoring tool (Kristof, 2020). This article addresses this gap by presenting lessons learned from developing ToCs within the strategic inter- and transdisciplinary research program Wings (Water and sanitation innovations for non-grid solutions) at Eawag, the Swiss Federal Institute of Aquatic Science and Technology.

The article begins by briefly presenting the Wings program, followed by a detailed description of how the tool was applied and adapted to the specific purpose and structure of the program. It then discusses the key challenges faced and how they were addressed by the program leaders (first and last author of this article). The article concludes by drawing practical implications for researchers, practitioners, and project or program leaders interested in applying the tool to increase the scientific and societal impact of their research. While these implications are derived from an interdisciplinary context, they also provide insights for transdisciplinary contexts.

7.2. Case study & methods

7.2.1. Case study

Wings is a strategic inter- and transdisciplinary research program, which was initiated in 2016 at Eawag. This ten-year program aims to explore and develop novel non-grid, small-grid and hybrid water and sanitation solutions in different socio-economic contexts from multiple disciplinary perspectives. Wings builds on past and current research projects from four Eawag departments (Process Engineering; Urban Water Management; Environmental Social Sciences; and Sanitation, Water and Solid Waste for Development) and combines them in a single program. Individual research projects are funded by different agencies and implemented collaboratively with actors from research, policy and practice. Projects are organized in four research pillars, with each pillar examining a typical socio-technical configuration (Markard et al., 2012) in at least one socio-economic context. Cross-cutting projects bridge between pillars and bundle conceptual and methodological needs of the program (see Figure 5)[12]. Table 8 presents a more detailed description of the program composition. The transdisciplinary dimension of the program aims to co-produce knowledge with actors from policy and practice. This is mainly accomplished at the individual project level. While the Wings program itself has a clear transdisciplinary ambition the program leaders have so far focused efforts to foster interdisciplinary communication, collaboration and integration within the program.

[12] The classification as ‘social science departments’ relates to the research focus and methods employed within these two departments, while the backgrounds of department members go beyond ‘classical social sciences’ (see Table 8) and in some cases even include original training in environmental engineering.

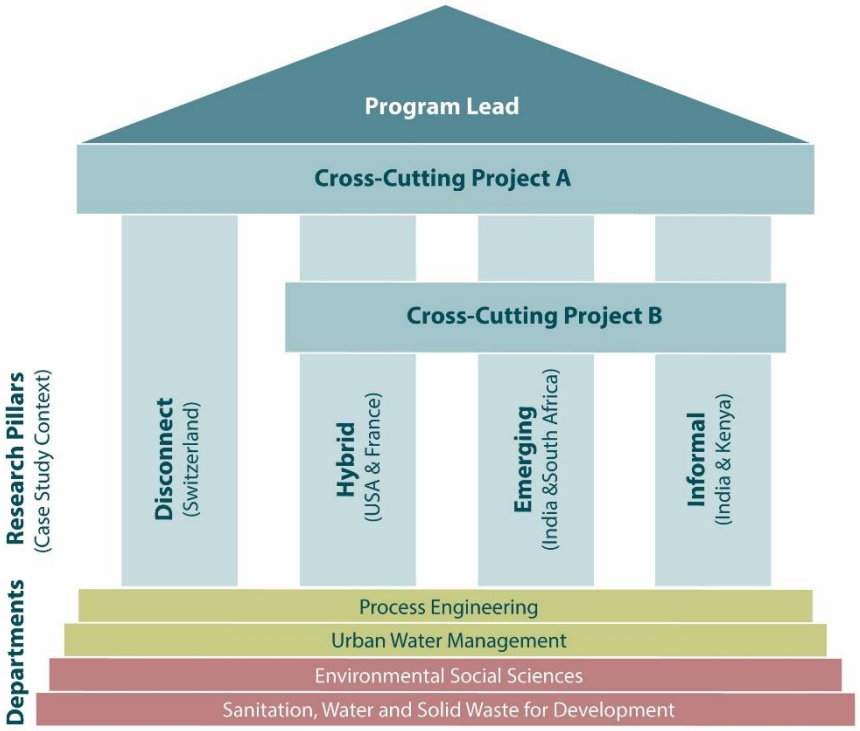

Figure 5: Wings Program Structure. Engineering Departments (Green) and Social Science Departments (Red)

This includes eliciting and integrating the diverse types of knowledge generated on the project and pillar level. Additionally, it involves developing a coherent and consistent long-term program strategy, i.e. aligning upcoming research proposals and catalyzing new integrated inter- and transdisciplinary research projects with the aim to support the transformation of the urban water sector towards sustainability (Eawag, 2018).

The decision to develop ToCs for Wings at project, pillar and program level was made for several reasons. In line with the key functions described in the literature, the tool was expected to support the research team in creating the 'bigger picture' about change processes in the urban water sector in different contexts (visioning), defining the program's contributions to these processes and identifying specific interventions in the short, medium and long term and related milestones at pillar and program level (planning). Additionally, the tool was intended to support the research team in monitoring change processes in the urban water sector and evaluating the outcomes of interventions defined at pillar and program level (monitoring and outcome evaluation). It was also intended to facilitate continuous reflection and learning about change processes in the course of the program (reflection and learning). Finally, the tool was expected to strengthen interdisciplinary communication and collaboration across all academic positions and departments involved and to foster integration across projects to identify, explore and generate synergies and add value to the projects. While a thorough analysis of the extent to which these expectations and intentions were effectively met is beyond the scope of this article, the authors envision another publication to address these questions adequately.

Table 8: Composition, purposes and focus of the program and its pillars (Scientists: SA = Scientific Assistant, PhD = PhD Student, PostDoc = Postdoctoral Researcher, GL = Group Leader, DH = Department Head, DM = Directorate Member; Departments: ENG = Process Engineering, ESS = Environmental Social Sciences, Sandec = Sanitation, Water and Solid Waste for Development, SWW = Urban Water Management)

Level	Pillars					Program
	Disconnect	**Hybrid**	**Emerging**	**Informal**	**Cross-Cutting**	
Purpose	Understand and address challenges and opportunities of alternative systems in high-income countries with highly centralized and ageing wastewater infrastructure	Technical development and optimization of urine separation and treatment as well as greywater recycling to regenerate water with high chemical and microbial quality	Support decision makers and niche players in middle-income countries on how to transition towards holistic alternative solutions that allow for meeting growing demands while recovering valuable resources	Understand the broader complexities of heterogeneous sanitation systems and give guidance for transitions to an improved state in informal settlements	Bundle conceptual and methodological needs of the pillars and/or the overall program in order to leverage synergies within the inter- and transdisciplinary research program	Explore and develop alternative urban water systems (=non-grid, small-grid and hybrid) from different disciplines and fields across different contexts and support socio-technical transitions and societal transformations towards sustainability
Research Focus	Where and when is it appropriate to disconnect from the central system and to implement alternative systems? Which potential infrastructure transition paths can be identified?	What are viable alternatives for full-scale applications that collect and treat the wastewater flows separately according to the type and concentration of their contaminants?	What is the potential of lead-markets for alternative systems in emerging markets characterized by rapid urbanization and an expanding middle-income population?	What are enabling and hindering environments for introducing alternative systems in informal settlements lacking basic services and decent housing?	What are institutional barriers of alternative solutions across different contexts? How can inter- and transdisciplinary integration be strengthened within the program?	How can alternative urban water systems be understood and analyzed from an inter- and transdisciplinary perspective?
Type of Projects	Disciplinary (1) Interdisciplinary (2) Transdisciplinary (2)	Disciplinary (3) Transdisciplinary (3)	Disciplinary (1) Interdisciplinary (1)	Disciplinary (1) Interdisciplinary (2) Transdisciplinary (1)	Disciplinary (2) Interdisciplinary (1)	Disciplinary (9) Interdisciplinary (5) Transdisciplinary (6)
Case Studies	Switzerland	France, USA	India, South Africa	Kenya, India	USA, India	All
Disciplines and Fields	Decision Analysis, Environmental Engineering, Human Geography, Transition Studies, Urban Water Management	Environmental Engineering, Innovation Studies, Process Engineering, Transition Studies, Urban Water Management	Environmental Engineering Decision Analysis, Human Geography, Innovation Studies, Transition Studies, Urban Planning	Environmental Engineering, Innovation Studies, Human Geography, Multi-Stakeholder Planning, Transition Studies, Urban Planning, Water Policy	Environmental Psychology, Innovation Studies, Inter- and Transdisciplinary Research, Human GeographyTransition Studies	Decision Analysis, Environmental Psychology, Environmental and Process Engineering, Human Geography, Innovation Studies, Inter- and Transdisciplinary Research, Transition Studies, Urban Water Management, Urban Planning, Water Policy
Departments	ESS, SWW	ENG, SWW	ESS, ENG, Sandec	ESS, ENG, Sandec	ESS	ESS, ENG, Sandec, SWW
Scientists	SA (1) PhD (4) PostDoc (1) DH (2) GL (1)	SA (2) PhD (3) GL (2) DH (1) DM (1)	PostDoc (1) GL (1) DH (1)	PhD (4) DH (2) DM (1)	PhD (1) PostDoc (2) GL (3)	SA (3) PhD (12) PostDoc (3) GL (6) DH (4) DM (2)
Actors/Partners	Federal, cantonal and communal authorities, engineering consultancies, professional associations, technology companies	Technology companies, architects, cooperatives, engineering consultancies, design offices, philanthropic foundations	Technology companies, utilities, authorities on different levels, policy-makers	Development agencies and banks, philanthropic foundations, NGOs, urban planners	Urban planners, authorities at different levels, utilities, inter- and transdisciplinary research community	Wide range of actors from research, policy and practice across different socio-economic contexts

7.2.2. Methods

Qualitative methods were used to document, analyze and synthesize the ToC development process (Wittmayer & Hölscher, 2017). These included bilateral interviews, participant observations during meetings, workshops and retreats, joint critical reflections via structured feedback sessions as well as research diaries (Hyers, 2018). Bilateral interviews and joint reflections with program members were used at different points to critically review the ToC process and provide feedback to the program leaders. Participant observations and research diaries were employed by the program leaders to individually document challenges experienced in leading the ToC process, formulate open questions and derive lessons learned for future meetings, workshops and retreats. Ex-post self-reflections following each meeting, workshop or retreat served to encourage the program leaders to jointly reflect on the ToC process and its intermediate results. Formal interviews, meetings, workshops and retreats were recorded with the consent of all participants and transcribed, providing an immensely rich empirical basis for analysis and ex-post self-reflection. The different challenges experienced and respective strategies developed during the ToC process were discussed and analyzed with 10 Eawag external experts in the fields of IDR and TDR, and enriched with contributions from the second and third authors of this article based on their experience with a range of other ToC processes. All program members validated earlier versions of this article.

7.3. ToC development process

There are many different ways of developing and presenting a ToC. Key components of a ToC are ‘activities’ (i.e. the actual project work, including research, communication and interaction with key actors), ‘outputs’ (i.e., the knowledge, innovations, capacities and/or relationships generated by the project), ‘outcomes’ (i.e., actions of key actors due to changes in knowledge, attitudes, skills, and/or relationships resulting from project or program outputs and interventions), and ‘impacts’ (defined as benefits realized in social, institutional, economic and/or environmental conditions resulting wholly or partially from a chain of events to which the research has contributed) (Belcher et al., 2020; Belcher et al., 2018). This chain of activities and outputs leading to outcomes and culminating in impacts are called ‘impact pathways’. ‘Interventions’, in turn, refer to a set of deliberate activities of a project or a program aimed at contributing to social change processes (Belcher & Palenberg, 2018).

Two structured retreats, twelve workshops, four program meetings and 24 bilateral meetings were used to develop ToCs at project, pillar and program level with the interdisciplinary program team at Wings.

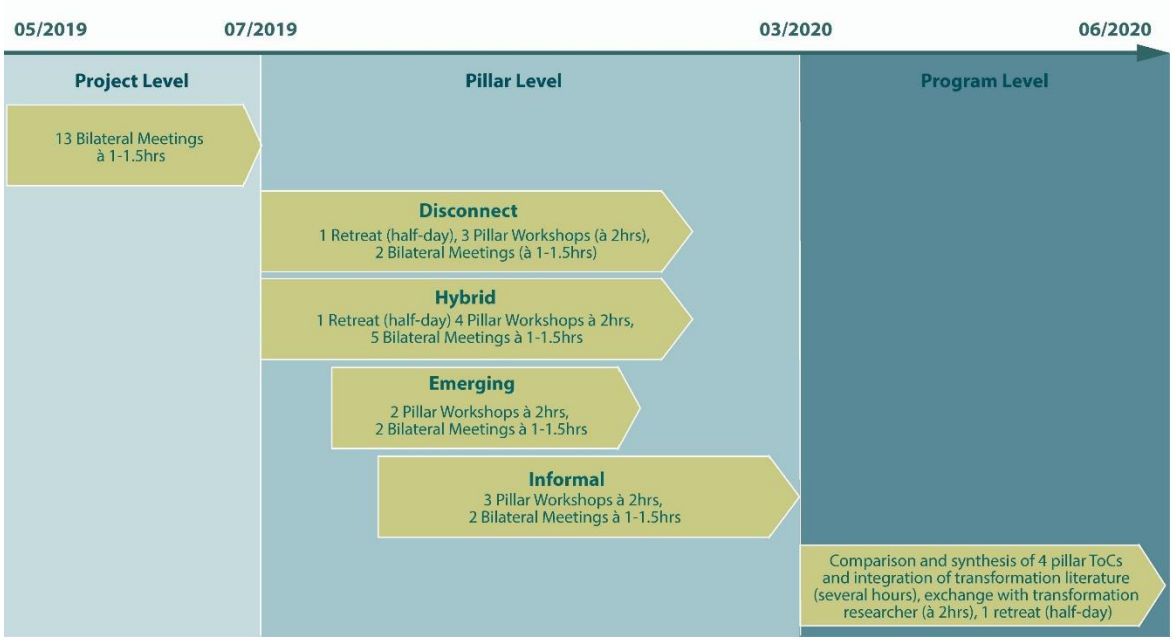

Figure 6: ToC development process at project, pillar, and program level

Figure 6 summarizes the process of developing ToCs at the different levels and illustrates the interaction formats and the amount of time invested at each level (see also sub-chapters 7.3.1-7.3.3).

Developing a ToC is a highly dynamic and iterative process that requires multiple feedback loops and periodic revisions. In the following, the ToC development process at each level (project, pillar, and program) will be detailed, distinguishing between two approaches: 'forecasting' and 'backcasting'. As many projects were already planned, the ToC process at the project level focused on forecasting; that is, analyzing the likely outcomes and potential impacts of one specific intervention or output. At the pillar and program levels, more emphasis was placed on backcasting, starting from the desired impact and moving 'backwards' to identify necessary long-term changes first, followed by changes in the medium- and short-term. This supported reflection about opportunities and constraints of change processes in the urban water sector, as well as identification of potential new research activities and interventions. In practice, 'forecasting' and 'backcasting' relate to the starting point of each approach; the program leaders iteratively applied and alternated both approaches throughout the process.

7.3.1. Project level

In a first series of 13 bilateral meetings with junior researchers (Scientific Assistants, PhD Students, Postdoctoral Researchers) and senior researchers (Group Leaders, Department Heads and Directorate Members) from both engineering and social sciences departments (see Figure 6), ToCs at project level were documented (forecasting) following the method described by Belcher et al. (2020). Each bilateral meeting modeled one element of a ToC (as opposed to trying to develop an all-encompassing project ToC at once). The focus was on mapping how a particular output (e.g. an analysis of policy options communicated through a policy brief) or a specific intervention (e.g. a stakeholder workshop designed to build shared understanding of complex problems and potential solutions) would inform and influence

actors' behavior. Provided with guiding questions one week before the meeting, researchers were asked in the meeting to first specify the overall purpose and intended societal impact of the project. They were then requested to develop a ToC starting from the selected output or intervention to define (i) which actors would be reached by the output or intervention (reach), (ii) how it would influence the knowledge, attitudes, skills and/or relationships of these actors (capacity change), (iii) what these actors would do differently as a result of these changes (behavior change), (iv) what direct benefits would arise from these changes (direct benefits), and (v) what implications these benefits would have on society (societal impact) (Mayne, 2015). For each project, the components were first mapped and clustered around an impact pathway (forecasting), and then placed within a nested spheres diagram ('sphere of control', 'sphere of influence', 'and sphere of interest') (Belcher et al., 2020). Finally, the underlying theoretical and contextual assumptions as well as risks and opportunities of the ToC were identified. Theoretical assumptions here refer to suppositions about the mechanisms or causal processes that explain why a change is expected, while contextual assumptions relate to the conditions of the system in which the project is operating (Belcher et al., 2020). Risks and opportunities, in turn, refer to uncertainties which, if realized, might hinder or help the achievement of project goals. All mapped ToCs were digitalized by the program leaders and validated by the respective researcher to ensure accuracy. An example is presented in appendix C.

7.3.2. Pillar level

Pillar level ToCs were developed iteratively between June 2019 and March 2020, starting with a two-day retreat with Wings senior researchers (see Figure 6). Researchers were divided into two groups, mixing engineers and social scientists, and asked to follow a step-by-step procedure facilitated by the program leaders and supported by guiding questions developed based on Vogel (2012a):

- Step 1: Each group developed an impact statement for one research pillar. The impact statement expressed a common vision and an overarching goal that the research pillar would aim to contribute to but would not be exclusively accountable for (Belcher et al., 2020). Although the strategic program ends in 2025, researchers were encouraged to reflect on an ambitious, but at the same time realistic and concrete goal for 2030.
- Step 2: Each group identified eight to ten actors they considered key to achieve the desired impact, classified them as either 'movers', 'floaters' or 'blockers', discussed their interests and rated their influence in realizing this change (Retolaza Eguren, 2011). Links were drawn between actors who already have interacted with each other (e.g. collaborations, exchanges). The colors indicated whether this relationship is primarily conflicting (red) or harmonious (green) (see Figure 7).

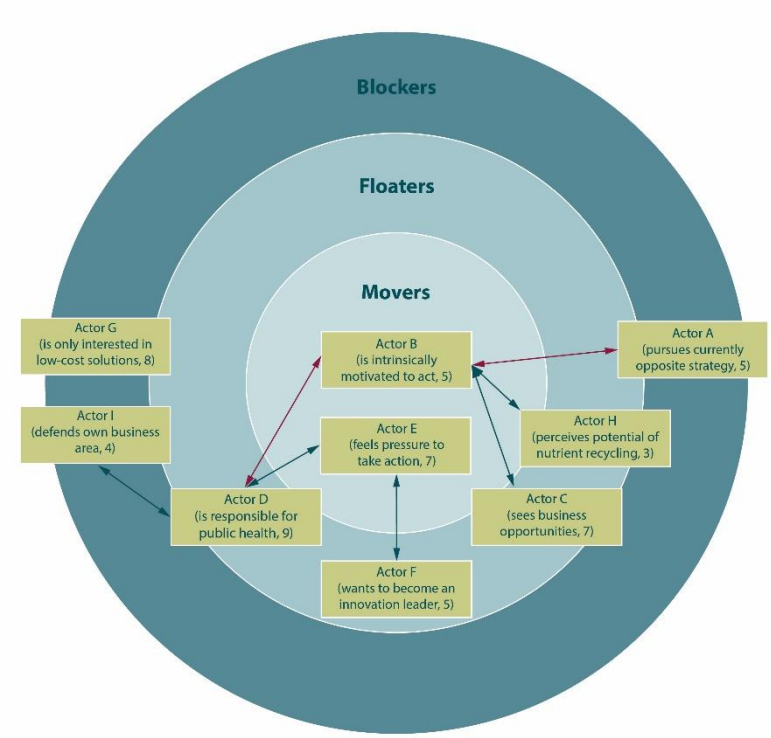

Figure 7: Actor analysis involving movers (in favor of the intended impact), floaters (undecided/no clear position) and blockers (clear position against the envisioned impact), their interest and influence in realizing the change on a scale from one (low influence) to ten (high influence), and whether relationships have been established, either being conflicting (red) or harmonious (green). Own illustration based on Retolaza Eguren (2011)

- Step 3: Based on steps one and two, each group articulated a sequence of necessary long-, medium-, and short-term changes, working back from the impact statement to identify the conditions that theoretically need to be in place for the intended higher-level changes to occur (backcasting).
- Step 4: Each group discussed already planned interventions and defined new interventions to support the changes, reflecting on potential actors to strategically partner and engage with over time.
- Step 5: Finally, each group presented their ToC in the plenary. Based on this discussion, a list of relevant gaps and open questions as well as underlying assumptions and uncertainties were compiled for further work.

All ToCs were developed iteratively, seeking validation from program members over the course of multiple meetings and workshops. The program leaders varied interaction formats (meetings, workshops, and retreats) and alternated group compositions in terms of scientific hierarchical positions, departments and disciplines (Table 8). Sticky notes were used to document and visualize the discussions. The program leaders recorded most meetings, workshops and retreats, and used the transcripts to extract implicit assumptions that they had missed while moderating the discussion and to feed them back into the iterative loops for further development of the ToCs. Once a pillar ToC was saturated and no new changes or interventions emerged during meetings or workshops, the program leaders organized a last workshop to prioritize interventions. Program members were asked to identify interventions of high,

medium, or low priority for achieving the desired impact and to explain their relative choice of priority. They were encouraged to identify and prioritize not only 'low-hanging fruit' interventions, but also more challenging ones, especially those with the most promising societal impact. Based on this prioritization, first roles, responsibilities and next steps were clarified, i.e. who leads what type of intervention together with whom and when. Each pillar ToC was discussed in one of the monthly Wings meetings and thereby further enriched (see again Figure 6). Figure 8 illustrates a generic model of the ToC developed at pillar level and its key components. For a more detailed example of a pillar ToC in terms of content, see appendix C.

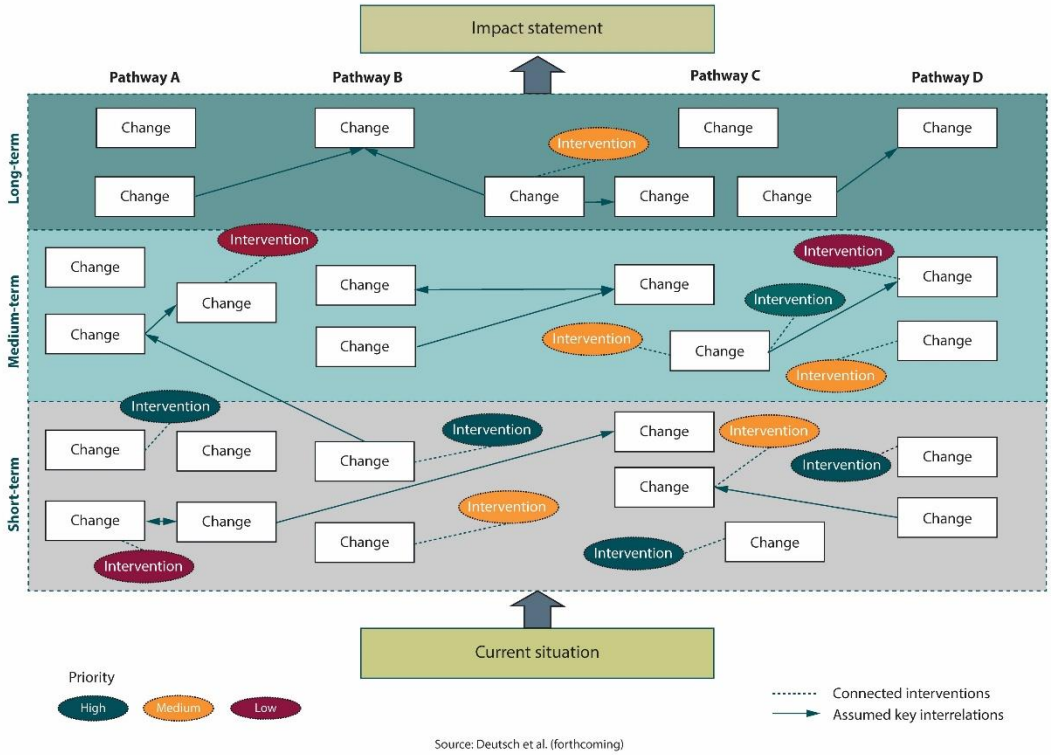

Figure 8: Generic ToC at pillar and program level developed within Wings (own elaboration)

7.3.3. Program level

The ToC at program level was developed by the program leaders in May and June 2020, building on the program impact statement developed by all senior researchers in the Wings Retreat in June 2019. At the retreat, all researchers, including the program leaders, were asked to bring a visual representation (e.g. a photograph or any other object) of the overarching goal of Wings. Supported by these visuals, the group formulated an impact statement. Once all pillar ToCs reached saturation, the program leaders analyzed and compared the four ToCs, identified similarities and differences across the pillars with regard to the long-, medium- and short-term changes and high-, medium- and low-prioritized interventions, aggregated changes and interventions at program level and clustered them around impact pathways that emerged during this process. The program ToC was then compared by the program leaders with insights from a current literature review on societal transformations (Kristof, 2020) and

subsequently enriched with key changes and interventions highlighted in the literature. The 'theory-grounded' and 'expertise-based' program ToC was discussed in a second retreat in June 2020 with the Wings junior and senior researchers, and subsequently revised.

7.4. Challenges and lessons learned

While leading ToC development processes at the project, pillar and program level, the program leaders responded to emergent needs from program members and adapted the approach accordingly, without losing sight of its key functions (Verwoerd et al., 2020, p. 32). In the following, the various challenges faced by the program leaders and lessons learned throughout these processes are discussed and reflected upon.

7.4.1. Investing and managing time efficiently, while dealing with heterogeneous perspectives

The formulation of impact statements at pillar and program level was informed by previous work, in particular the definition of shared goals, developed through numerous workshops and meetings since beginning the program in 2016. With this foundation, the impact statements were developed quickly (30−45 min). Discussions about long-, medium- and short-term changes as well as the identification and prioritization of interventions required several iterations over a longer period of time (see Figure 6). Program members tended to agree on the 'what' questions (i.e. the desired impacts) quite quickly, but perspectives diverged on 'how' the desired impacts can be achieved and 'how' the prioritized interventions can be operationalized. They had different views on how fast change processes develop in the urban water sector, which pathways to focus on, and which actors to engage with to induce and support these change processes. This heterogeneity reflected not only different disciplinary perspectives, but also different worldviews (O'Rourke et al., 2019) and prior experiences of program members, which tend to be understated or neglected in the literature (Ives et al., 2020). The program leaders created space to explore different scenarios (pace of change in the urban water sector and role of different actors) and their consequences for the program's research activities in more detail. In some cases, it became apparent that previously assumed 'diverging perspectives' were in fact complementary, rather than contradictory (e.g. different actors were more or less important at different points of time). In other cases, however, differences remained (e.g. pace of change), but awareness was raised among the program members about the potential implications of different scenarios on their research and the overall program. As stated by one program member:

"I think the key issue here is: what do we take out of this discussion? If [program member] X is right, what difference does this make? If we are unprepared for this development [acceleration of change], we make a mistake. At the same time, it is only a hypothesis. If we now invest all our resources in preparing for this [change], and then it doesn't happen, this would also be undesirable. These two things, we need to balance."

Overall, the program leaders did not necessarily aim for a consensus among program members, but a common ground that would still "recognize and value difference" in perspectives instead of assimilating them (Klenk & Meehan, 2015, p. 166).

Arriving at integrated answers to the 'how' questions, required program members to commit substantial time to this inherently iterative process (Oberlack et al., 2019), in addition to their already high workloads. As Maasen and Lieven (2006, pp. 402-403) emphasize, while "there is always time pressure" in research, "the problem is aggravated" in inter- and transdisciplinary endeavours as "heterogeneous inputs" need to be integrated. The initial strategy to iteratively develop the ToC by asking for individual written inputs from program members after meetings, workshops or retreats did not prove beneficial, since senior program members in particular usually have little time to comment on ToCs beyond formal interaction formats. In practice, the ToC process benefitted most from face-to-face interactions during meetings, workshops, and retreats. The time constraints of senior program members required program leaders to produce tangible outputs during such meetings, workshops, and retreats to keep program members engaged. This in turn required thorough preparation i.e. getting familiar with the tool, developing step-by-step guidance, recapping arguments from previous interactions to steer follow-up discussions and set clear and realistic goals for each encounter. To cope with the often limited time available by program members, the program leaders alternated different interaction formats to develop the ToCs further (i.e. formal small and large group workshops, bilateral meetings as well as informal coffee and lunch exchanges) and co-defined the specific purpose of each interaction with program members. Although not all tasks were done in formal meetings, it proved to be essential to focus on the most important and intellectually challenging tasks when meeting face to face (Hampton & Parker, 2011). These strategies helped to "balance between a too detailed, time-consuming mapping process and a superficial, 'quick & dirty' approach that reproduces stereotype thinking and adds no value" (van Es et al., 2015, p. 55).

7.4.2. Balancing between the concrete and the abstract

Program members initially discussed ToCs on a rather abstract level, which made it difficult to elicit implicit assumptions and brainstorm concrete research activities and interventions. Moving from abstract concepts to specific 'people-oriented' statements is a major challenge also found by van Es et al. (2015, p. 41). To ground the discussion empirically, program members were encouraged to identify key actors involved in the change process and specify the behavioral changes required by these actors to enable higher level changes (i.e. who does what differently at which points of time and why?). In addition, they were asked to be realistic and deliberate about the underlying mechanisms of change that can be leveraged (e.g. what is needed beyond knowledge for actor X to contribute to change in organization Y?), while avoiding 'leaps of faith' (Vogel, 2012a, p. 14) and refraining from wishful thinking (e.g. lead markets for new technologies will emerge as a result of research articles).

Achieving a good balance between the concrete and the abstract, is seen as a key feature of a rigorous ToC (Vogel, 2012b) and proved more difficult to attain in some pillars than in others. While the pillar 'Disconnect' focuses on only one socio-economic context (e.g. Switzerland), but builds on a large number of past and current research projects, which have generated large amounts of in-depth contextual knowledge, the pillar 'Informal' encompasses case studies in several countries (e.g. Kenya and India), involving fewer research projects, and at the same time more diverse and complex actor constellations. To address this challenge, developing and documenting ToCs at pillar level required each pillar team to determine an appropriate degree of specificity and to involve especially Scientific Assistants, PhD Students, and Postdoctoral Researchers with good contextual knowledge.

7.4.3. Ensuring appropriate diversity in group composition while balancing comfort and discomfort

"Getting the right mix of diverse group members" (Harvey et al., 2018, p. 195) to develop the ToCs in smaller workshops was another challenge. Bringing implicit assumptions to the surface proved to be more difficult in 'homogenous' groups, where group members reaffirmed rather than challenged each other and discussions remained abstract (see subchapter 7.4.2.). In these cases, it was the program leader who critically interrogated unquestioned underlying assumptions, often as a series of questions and answers between the program leader and the rest of the group. 'Homogenous' here refers to a lack of diversity in terms of scientific disciplines, research projects, hierarchical positions, experiences and prior collaborations. The program leaders' assumption that the ToC process would benefit from well-established working groups turned out to be partly flawed. The members of one long-established group, for example, did not break out of their 'usual way of reasoning' about transformations in the urban water sector. While well-established working groups tend to entail a lot of trust, which is beneficial for collaborations, they also tend to limit critical discussions about each other's assumptions. To deal with this, it proved useful to arrange new group compositions by bringing together program members who had not previously collaborated closely, while also ensuring breadth of disciplines, diversity of departments and variety of hierarchical positions involved in these discussions. Junior researchers in particular provided detailed empirical insights and new ideas, which also helped to ground abstract discussions in concrete real-world examples (see subchapter 7.4.2). Hence, trust and well-established groups are not necessarily key ingredients alone for productive interdisciplinary discussions. While diversity proved essential for eliciting implicit assumptions and steering critical discussions, it brought with it yet another challenge: the need to strike a balance between an "understimulating comfort zone and an overly disruptive discomfort zone" (Freeth & Caniglia, 2020, p. 254). The program leaders were therefore tasked with carefully managing this balance to create a "learning zone", by treating each perspective with genuine curiosity and avoiding hasty judgments (see subchapter 7.4.1.).

For facilitating the integration of different perspectives, the program leaders tested two approaches. In some cases, program members were asked at the start of the workshop to individually brainstorm about necessary long-, medium-, and short-term changes and note their ideas on sticky-notes before starting a

joint discussion. In other cases, the program leaders initiated group brainstorming and discussion right away, while jointly formulating and synthesizing the ideas on sticky notes. This latter approach proved to be more effective as terms and ideas could be clarified and discussed in depth before being summarized and sticked to the pin board. In cases where each program member documented their own ideas separately prior to discussion, the ToC tended to reflect a mosaic of individual perspectives rather than an integrated picture, and therefore required more integrative efforts from the program leaders afterwards.

7.4.4. Fluctuating between reservations and appreciation

At the beginning, the term 'Theory of Change' was met with reservation; some program members argued that the term is extremely fuzzy; others contended that a 'Theory of Change' is not a proper 'theory'[13]. The program leaders responded to this concern by stressing that assumptions are rooted to a certain extent in scientific evidence, but are also informed – to an even larger extent – by mental models (Johnson-Laird, 1983; van Es et al., 2015), worldviews and prior experiences of each program member. They further explained that, although it is uncertain to what extent these assumptions hold in reality, it is crucial to make assumptions explicit since they influence researcher's and a program's strategic decisions. By making them explicit, assumptions become hypotheses which can be tested, challenged and refined by different perspectives from policy and practice (Schneider, Giger, et al., 2019). Such explicit discourse enables learning on how change unfolds in the particular contexts of each research pillar (Belcher et al., 2020), and can inform future research activities and collaborations among different actors. While some program members found these explanations useful for understanding the origin of the term ToC, some reservations concerning the term remained. It could be discussed to what extent renaming the tool might prevent similar misunderstandings in other projects or programs. In addition, the initial reservations highlight the need for clarifying terms and outlining the purpose and utility of ToCs clearly both prior to, but also throughout the development of a ToC.

Another concern was that the ToC was not sufficiently grounded in the literature on societal transformation, as also argued by Archibald et al. (2016). To deal with this concern, the program leaders compared the ToC on the program level with insights from a literature review on societal transformations (Kristof, 2020), exchanged with the author of this review on the ToC at program level, and revised the ToC based on her feedback. They then discussed the 'theory-grounded' and 'expertise-based' ToC with program members (see subchapter 7.3).

The ToC development also showed that engaging with different societal actors requires researchers to adapt their research practices and go beyond their traditional 'observer roles'. The diversification of roles in different contexts and different points in time, and how to delimit them from other actor groups,

[13] The term "Theory of Change" may be misleading to some because it implies a single theory. In fact, a theory of change is a set of hypotheses based on several theories about cause and effect in a particular context.

was critically discussed several times throughout the process. One program member linked this discussion to researchers' competencies in inducing and supporting such transformation processes:

"What are our core competencies or core mandates as researchers? So which core competencies can we bring into this whole ToC in order to enable things? … It's not that we have that know-how to change things as a core skill."

The reiteration of discussions on roles and competencies revealed different perspectives on researcher's roles, but also the challenge of 'role-strains' in inter- and transdisciplinary programs (Parker & Crona, 2012, pp. 265-266). Researchers are not only confronted with multiple demands stemming from their disciplinary fields, but also need to acquire a new skill-set to engage in inter- and transdisciplinary research modes. The ToC development helped to steer a discussion on which competencies are lacking and need to be developed within the program, and which competencies could be covered by other actor groups. Related to this, some program members also raised concerns about being held accountable for what is stated in the ToC and expected to contribute to all identified necessary changes on top of their already high workload:

"I find it great. There is everything in there [the ToC] what is needed, but at the same time this is the problem of the whole story. When I look at this and imagine that we have to do all of it, then I feel a bit overwhelmed."

The program leaders clarified that the intention is not to put all the responsibility on the program members, but to use the emerging 'bigger picture' for strategy development. This involves taking conscious decisions about the various roles program members assume in different contexts (facilitator, collaborator, enabler, etc.), the different societal actors they engage with and the future research they pursue, hence overall leveraging synergies to induce and support societal transformation processes in a coherent and strategic manner. In addition, it should help program members to prioritize interventions and allocate resources (e.g. personnel, financial), thus facilitate strategic long-term planning.

However, the expressed concern points to a structural tension inherent to inter- and transdisciplinary research programs (Turner et al., 2015): research practices are strongly determined by the current incentive structure of academia, which values a large number of disciplinary publications in short time. Inter- and transdisciplinary collaborations require long-term time investments and produce a broader range of outputs but fewer academic publications per unit of time or effort (Belcher et al., 2015). Program leaders can use tools and strategies to encourage researchers to reflect upon their roles, the societal relevance of their research and can support them in adapting their research practices accordingly. However, these efforts can only bear fruit if "possible conditions for [these] new practices" are created and "room for maneuver" is provided (Åm, 2019, p. 175). To fully realize the potential of ToC-guided interventions, it is essential to recognize and value policy- and/or practice-oriented outputs such as policy briefs or synthesis reports alongside traditional academic publications when evaluating

researchers, teams and programs, particularly with regard to career or funding decisions (Schikowitz, 2020, p. 17). The 'old' incentive structures in academia, make it hard to live up to the ambitions of 'new' inter- and transdisciplinary research modes (Schmidt & Neuburger, 2017). The program leaders addressed this tension by focusing on some interventions that are synergistic with on-going or planned disciplinary activities and others that put more emphasis on inter- and transdisciplinary efforts with new activities and a broader range of collaborators and actors, aiming to contribute to transformation beyond individual project boundaries (Turnhout et al., 2020). The latter required strategic in-depth discussions to adequately deal with the resources of individual members available.

All concerns notwithstanding, program members expressed their satisfaction with the enriched version of the ToC during a virtual program retreat in June 2020. The benefits of the ToC approach (e.g. understanding one's role and contribution in different contexts, identifying interdependencies between disciplines as well as between science, policy and practice) became apparent and more tangible over time, which resulted in growing recognition and appreciation of the tool. This was summed up by one program member:

"I would say, what we now have is a mapping of the socio-technical systems. So, how the different parts are interconnected and interdependent. I guess that's a sort of an added value … that you see there's lots of interconnections as to what we want to achieve in Wings. And I guess what is also very important … is that we adopted some systemic perspective."

To deal with reservations, however, it was crucial to explicate the added value of the tool by explaining the key functions and intentions behind its application and to remain responsive to emergent needs and constructive criticism from program members.

7.4.5. Fulfilling service and science roles

During the ToC process, the program leaders assumed both 'service' and 'science' roles (Bammer et al., 2020; Hendren & Ku, 2019; Salazar et al., 2019). In the service role, the program leaders were, for instance, confronted with a steadily growing amount of data about the program members' implicit and explicit assumptions. To cope with and capitalize on this data deluge, it was imperative to plan from the start how to collect and systematize data (e.g. implicit and explicit assumptions) and how to use this data to strategically lead the ToC process; otherwise important assumptions can be easily neglected. It was crucial to be consciously selective and purpose-driven to successfully cope with the complexity (van Es et al., 2015, p. 49), as was documenting and visualizing data on a regular basis, creating 'material artefacts' (Pennington et al., 2013) to ease the discussion in meetings and keep program members motivated and engaged.

Integrating the various perspectives from different disciplines and different projects into a comprehensive whole constituted a substantial cognitive challenge, and a critical part of the 'science' role of the program leaders. This integration was promoted to a large extent by the two program leaders

beyond meetings by identifying relevant gaps and open questions, and determining critical connections and potential synergies between the ToCs at pillar and program level. This was key for allowing the bigger and more integrated picture about change processes in the urban water sector to emerge. Assuming both roles required not only skills in facilitation (Rees, 2001; Schwarz, 2017), but also expertise in the field of the program's topic (Defila & Di Giulio, 2018a, 2018b) to be able to act at the boundaries of the different disciplines involved in the process and recognizing critical connections between them (Hendren & Ku, 2019). Expertise in both facilitation and integration further involves personal dispositions such as openness, empathy, flexibility, adaptability and persistence (Augsburg, 2014; Fam et al., 2017; Guimarães et al., 2019), 'contributory expertise' in building bridges and 'interactional expertise' (Collins & Evans, 2002) "to work effectively and knowledgeably with a team" (Bammer et al., 2020, p. 2). Hence, the program leaders not only led program members step-by-step through the process and facilitated discussions, they also integrated the various contributions, including their own, into a more coherent and consistent whole.

Integrating heterogeneous contributions requires, however, not only a significant amount of cognitive effort (Harvey et al., 2018), but also emotional (see 7.4.3. 'balancing comfort and discomfort') and social (see 7.4.4. 'fluctuation between reservations and appreciation') efforts (Boix Mansilla et al., 2016). Overall, assuming this integrative 'science role' (and balancing it with the 'service role' of coordination, facilitation, documentation and visualization), implied a significantly higher workload than initially expected, and required flexibility and adaptability by the program leaders throughout the process. However, assuming both roles offered valuable opportunities to both develop and strengthen expertise in facilitation and integration, all of which is transferable to other IDR or TDR endeavors (Hampton & Parker, 2011).

7.5. Conclusion and outlook

The growing interest in ToC reflects the increasing demand for tools which support inter- and transdisciplinary projects and program leaders, ultimately aiming to strengthen the link between research and societal impact. This article presented how ToCs were developed for visioning, planning, communication, collaboration, integration and reflection across departments, projects and disciplines within the inter- and transdisciplinary program Wings. Challenges included managing time constraints, balancing the concrete and the abstract, ensuring diversity in group composition, fluctuating between reservations and appreciation, and fulfilling both service and science roles. The article derived and summarized lessons learned from leading a ToC process within an interdisciplinary setting. These insights are also transferable to transdisciplinary contexts, and can support other program leaders in their ambition to apply ToCs in their own research programs.

However, the ToCs developed within Wings also have limitations. There is a risk that program members equate the developed ToCs, which represent researchers' assumptions about change, with reality itself, if they are not further contrasted and complemented with perspectives from policy and practice. Furthermore, since the program leaders took a very proactive role in leading this process from the very beginning, there is some risk that ToC ownership rests with the program leaders and not with program members. Valters (2014, p. 20) supports this concern by stating that during ToC workshops there "was a commitment to a broader reflective approach" about change, but participants were not necessarily "wedded to the use of ToCs per se". There is the risk that the ToC process could lose momentum if not driven forward by the program leaders.

To address these concerns, next steps in the ToC process include the further definition of roles and responsibilities for all ToCs within Wings, specifying who leads what type of intervention together with whom and when, including the subsequent implementation of prioritized interventions. To meet the concern that the ToCs developed so far mainly capture the researchers' assumptions about change in the urban water sector, workshops will be organized with actors from policy and practice to jointly discuss and refine the ToCs. The ToCs at pillar and program level will be revisited every six to twelve months in order to contrast the researchers' initial assumptions against actual changes in the urban water sector, using qualitative and quantitative indicators (based on Hitziger et al. (2019); Maag et al. (2018) and Posner and Cvitanovic (2019)) and the outcome evaluation approach suggested by Belcher et al. (2020).

This will also allow the program to monitor unexpected and unintended outcomes of the interventions implemented, providing insightful lessons about key mechanisms of change. This way, the ToC remains a living and dynamic product and allows for continuous learning across departments, projects and disciplines. Overall, ToCs provide substantial potential for future research by providing a framework to identify and analyze the common pitfalls of disciplinary assumptions about change in contrast to the realities of social change. In addition, they can demonstrate the potential for outcomes and impacts of inter- and transdisciplinary programs for research funders. The authors acknowledge that the use of ToCs can be combined with other tools, which can support inter- and transdisciplinary planning for societal impact by documenting and reflecting on expected changes from research interventions (Network for Transdisciplinary Research, 2020). Documentation and reflection of such experiences is strongly encouraged to support continuous learning for research effectiveness. Furthermore, future IDR and TDR that applies ToCs could further explore and document experiences to what extent ToCs serve as effective boundary objects (Star & Griesemer, 1989) for crossing boundaries between different disciplines, but also between research, policy and practice. It will be particularly interesting to analyze to what extent the development of ToCs enhances inter- and transdisciplinary communication, collaboration and integration by drawing from the empirical evidence gathered throughout this process.

8. Action-oriented processes, outcomes and outputs

Throughout the course of my thesis, I engaged with several stakeholders and discussed and shared my results in different communities and at different levels via 'non-traditional' formats. Given that my thesis deals with ID and TD research, several key stakeholders belong to the scientific domain themselves. These stakeholders are researchers doing ID and TD, leaders of ID and TD projects or programs, funders, directorates/executive boards of research institutions and science policy makers (see again chapter five). To illustrate how my thesis has contributed to certain processes, outcomes or outputs, I will not only distinguish between these different stakeholder groups, but also structure them according to the international, national, (cross-) institutional and program levels.

International level:

- Blog post on lessons learned for integrating different perspectives via Theories of Change/ Institute for Social-Ecological Research (ISOE) in Germany: I synthesized insights from chapter seven in order to contribute to the ISOE blog on how to integrate different perspectives in the context of sustainability transformations by applying the integrative method «Theory of Change»: "*Geht das, verschiedene Perspektiven für eine Nachhaltigkeitstransformation unter einen Hut zu bekommen? – Einblicke in den Ansatz „Theory of Change"*" (Deutsch & Hoffmann, 2022) *(researchers, ITD leaders)*
- Blog post on lessons learned for leading ITD integration / The Australian National University (ANU) in Australia: I synthesized insights from chapter seven and our experiences with leadership challenges within the Wings program to contribute to the Integration and Implementation Insights Blog by ANU: "*Integration in inter- and transdisciplinary research: how can the leadership challenges be addressed?*" (Deutsch & Hoffmann, 2023) *(ITD leaders)*
- Blog post on the development of Theories of Change on 'integration experts' / Global Alliance for Inter- and Transdisciplinarity (ITD Alliance): As a member of the working group 'Integration Experts and Expertise' of the Global ITD Alliance, I contributed at several instances to the development of Theories of Change to support integration experts and expertise in the future: "*Towards a theory of change to institutionalize integration experts and expertise*" (The Aeschiried Integrators, 2023) *(researchers, ITD leaders)*

National level (Switzerland):

- Opinion article / Bulletin of the Swiss Academy of Humanities and Social Sciences (SAGW): Within the rubric «the last word» I contributed with insights on the daily challenges of ID and TD from the perspective of an early-career researcher and made a couple of suggestions for improving conditions: "*Interdisziplinär forschen - kein Kinderspiel*" (Deutsch, 2021) *(researchers, directorate members, funders, science policy-makers)*

- Practice report / Td-net Toolbox: Methods and tools for co-producing knowledge (Swiss Academies of Arts and Sciences): Based on insights from chapter seven, I contributed with a practice report to the td-net toolbox to support other researchers in developing Theories of Change in large ITD programs (Deutsch & Hoffmann, 2021a) and gave a lecture within the Monday Seminar Series of td-net in November 2023 *(researchers, ITD leaders)*
- Recommendations / Report Lighthouse Programmes in Sustainability Research and Innovation (Swiss Academies of Arts and Sciences): Based on chapters five and seven, I contributed concrete design options to a new report on setting up integrated funding programs supporting sustainable development in the future (Wuelser & Edwards, 2023) *(ITD leaders, funders, directorate members, science policy-makers)*

(Cross-) Institutional level:

- Peer-to-Peer exchange across WSL, Eawag and MeteoSwiss: By organizing bi-annual focus groups with the six leaders of the three ITD initiatives, my thesis contributed to strengthening collaborations and peer-to-peer exchange across different research institutions (WSL and Eawag) within the ETH domain, and between these two research institutions and a Swiss federal office (MeteoSwiss). All six program leaders reported several times throughout the accompanying research that they valued the regular meetings and exchange, and the overall collaborative space that the thesis has created (*ITD leaders*)
- Reflection workshops on lessons learned for doing ID and TD at Eawag: In June and July 2023 I co-organized two reflection workshops for the ITD program Wings and the ITD project Eco-Impact – two Eawag internal initiatives, which already ended. The goal was to derive and discuss lessons learned for future ITD projects and programs. The empirical insights gained through accompanying the Wings program informed the workshop substantially. Three (former and current) Eawag directorate members were present at these workshops *(researchers, ITD leaders, directorate members)*
- Action Guide: Strategies to establish inter- and transdisciplinarity in your research organization: Based on my empirical insights from chapters five, six and seven, I contributed to the action guide by Dettwiler et al. (In preparation), which aims to support directors and executive boards of research institutions in creating more favorable conditions for ID and TD research *(directorate members, science policy-makers)*

Program Level:

- Appointment of 'Integration Experts' within SWEET Program of BFE (Swiss Federal Office for Energy): After several formalized exchanges with representatives of the SWEET program on how to enable integration within large ITD research programs, sharing our results from the case study Wings, and discussing the importance of 'integration experts' (Hoffmann, Deutsch,

et al., 2022), funders in their latest call made it obligatory for consortia to appoint integration experts in order to take ID and TD integration seriously and to assign explicit resources to it on the program-level *(funders)*

- Diffusion of integrative methods into programs Extremes, NCCS and Wings: For each focus group meeting with the six program leaders, I employed and tested integrative and creative methods myself to elicit discussions and integrate their experiences (e.g. a reversal technique, Soft System Methodology) (Lungershausen, 2017; Pohl, 2020). Program leaders picked those methods up which they had experienced themselves and applied them during their own program meetings. The same applied to Wings program members: some of them started using the reversal technique and the Theory of Change in other ITD projects (*researchers, ITD leaders)*
- Reflexive stimulus within the programs Extremes, NCCS and Wings: The interview guideline and the way it was designed for retroductive reasoning proved to be an effective "reflexive stimulus" (Willis, 2019, p. 450). Several interviewees reported that they had enjoyed the interview (and were open to spend more time than the agreed 1.5hrs), particularly because they appreciated having time to reflect upon questions they consider crucial (e.g. what is integration in concrete terms? Who is responsible for integration?), but rarely take the time to reflect upon such matters in a structured manner. Similarly, the program leaders reported that the bi-annual focus groups constituted for them so-called «islands of reflection» in the middle of heavy workloads (*researchers, ITD leaders*)

Finally, in collaboration with the cartoonist Christof Stückelberger and my supervisor and Wings program leader Sabine Hoffmann, I created a humorous series of 15 cartoons displaying everyday scenes of inter- and transdisciplinary integration. These cartoons can support others in communicating key messages about ID and TD integration in a humorous way[14]. Five examples of these cartoons are displayed throughout various chapters of this thesis, while the remaining ten can be found in the appendix. We applied a reversal technique (Lungershausen, 2017) – the headstand strategy – in different ITD project and program contexts, asking people to brainstorm what strategies, actions and behaviors are useful for making sure that integration fails in their projects or programs. By reversing the question of interest (i.e. How to enable integration?) in a first step, the technique allowed participants to approach the topic of ID and TD integration from a humorous and lighter angle. In a second step, we asked participants to assume again an 'enabling perspective' and to translate their insights from the headstand strategy into future enabling actions for integration. The cartoons display this 'headstand-strategy', providing insights into what (not) to do when striving to advance integration from an individual and a leadership perspective. An exhibition of the cartoons is envisioned at Eawag in September 2024 and at the ITD Conference in Utrecht in November 2024.

[14] The cartoons can be used via a creative commons license for non-commercial purposes (CC BY-NC-ND 4.0) by stating the following reference: © Eawag: Lisa Deutsch & Sabine Hoffmann; Stückelberger Cartoons: Christof Stückelberger, CC BY-NC-ND 4.0

9. Synthesis

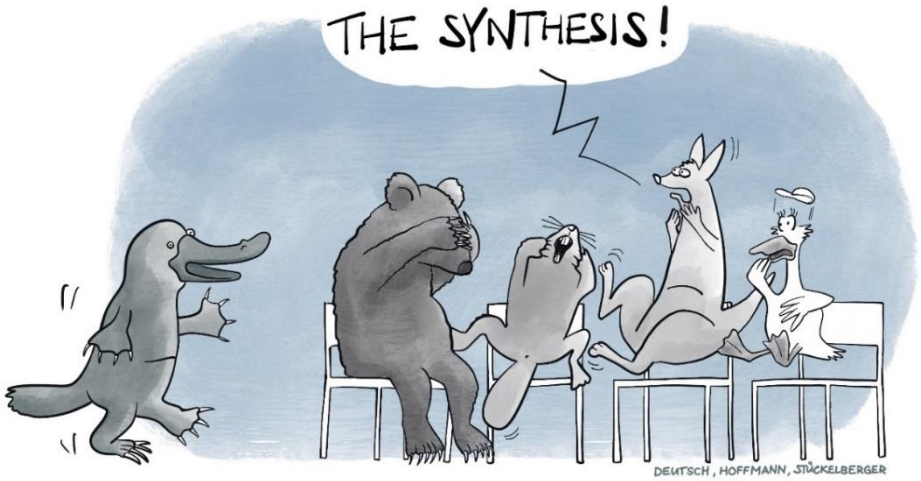

Image 2: © Eawag: Lisa Deutsch & Sabine Hoffmann; Stückelberger Cartoons: Christof Stückelberger, CC BY-NC-ND 4.0

In light of the urgency of complex societal problems, and a changing science-society contract (Gibbons, 1999), the need for integration across disciplines, sectors, policy fields and practice is likely to become rather more than less important in the future. Research institutions, funders and governments at different levels are faced with the question of how they want to position themselves in the face of multiple complex problems and whether they want to build up structures and provide resources to be able to better deal with them in the future. As a consequence of lessons learned from the Covid-19 pandemic, the Swiss Federal Council (2023), for instance, has endorsed the formation of permanent scientific thematic clusters on crisis-relevant topics in order to activate the science-policy interface more efficiently in the future. In the same vain, the Swiss Academies of Arts and Sciences has argued in favor of large integrated funding programs that enable inter-, transdisciplinary and impact-oriented collaborations on sustainability challenges in the long term (Wuelser & Edwards, 2023). However, while important, this thesis has argued that the mere existence of such inter- and transdisciplinary spaces does not automatically guarantee that integration also happens. Given that contemporary modern societies in general and academia in particular are characterized by high degrees of specialization and differentiation of knowledge, this thesis showed that non-integration must still be assumed to be the default-mode. This implies that integration needs to be actively pursued and enabled, otherwise business-as-usual i.e. non-integration simply continues. How this can be done was the focus of this thesis. This thesis argues that integration requires

1. *structures* i.e. enabling conditions at different structural levels to provide the fertile ground upon which integration can thrive, and the actions of multiple actors to create such conditions (contribution 1);
2. *agency*, i.e. integrative leadership to make sure that integration is actively and continuously pursued (contribution 2), and
3. *means*, i.e. integrative methods to establish common ground, facilitate discussions and identify concrete joint activities and outputs (contribution 3).

The key contributions in these three areas will be outlined in more detail in what follows. In addition, a cross-cutting contribution of this thesis was the generation of action-oriented knowledge (Fazey et al., 2018) for different actor groups, hence intending thereby to bridge theory and practice, or put differently, the abstract and the concrete.

9.1. Contribution 1: A structure-agency perspective on ITD integration and scope for action

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There are multiple ways to study the enabling and hindering factors of ITD integration as outlined in chapter two. This thesis has contributed to this field by studying ITD integration through a structure-agency lens in line with a critical realist perspective. Such a lens has various advantages as it allows us to adopt and combine several perspectives on the 'how-to' of integration: First, the developed structure-agency framework (chapter five) embraces a bigger picture view on integration by distinguishing conditions at the individual, team, program, institutional and socio-political level (*open system perspective*). Such a perspective can support in particular researchers and ITD program leaders in diagnosing and understanding where structural challenges potentially come from (Wren & Swatez, 1995). The framework further contributes to the field by conceptualizing these levels as nested spheres and thereby acknowledges their embeddedness and the interplay between them. Mechanisms at different levels operate in an open system, which makes a successionist view on causality with assumptions like "when A then B" obsolete. In an open system, the causal power of certain mechanisms can be counteracted by the realization of powers emerging from other mechanisms (Sayer, 2000, p. 15). This has consequences for the practice of integration: It means that favorable conditions at one level (e.g. sufficient funding on the program level) can still be counteracted or diluted by less favorable conditions at another level (e.g. program team composed of alpha animals, see image 3). It further means that whether integration happens or not cannot be expected to solely rely on motivated individual team

members or a passionate ITD program leader (although both are important enabling conditions). Integration efforts by team members and program leaders need to be backed up by supportive structures such as resources, rewards, incentives and sanctions.

Second, via a structure-agency lens, this thesis identified concrete scopes for action to create more favorable conditions for integration (*action-oriented perspective*). The conceptual framework (chapter five) allows 'needs for action' (e.g. consider the intrinsic motivation of individuals when they join an ITD program) at a certain level (e.g. team level) to be identified and links them with the potential 'power to act' and sphere of influence of concrete actor groups (individual team members, project/program leaders, directors/executive boards of institutions, funders, or science policy-makers). Understanding the overall conditions conducive to enabling integration more in-depth constitutes an important basis to encourage these actor groups to make "future investments in large-scale team science initiatives more strategic (i.e., scientifically productive and financially cost effective)" (Stokols et al., 2008, p. 112). Enabling integration requires us to provide impetus on different levels or, if not possible (e.g. on the socio-political level), to think about mitigation and coping strategies (chapter six and seven) to absorb these disadvantageous aspects on another level. Hence, without a comprehensive policy approach (Müller & Kaltenbrunner, 2019, p. 496) that creates enabling conditions at multiple levels, ITD endeavors are not likely to succeed. For instance, ITD integration is still inherently a high-risk high-gain endeavor (Kilburn, 1990; Leahey et al., 2017). However, the risk should only be content- and not career-related (Lyall, 2019). If the promise of ITD integration is intended to be truly realized, it lies within the sphere of influence of multiple actors to take supporting actions in this direction. The insights presented in chapters five and six can inform policies for strengthening ID and TD integration and the design of future ID and TD programs in this respect (Bruce et al., 2004).

Finally, by employing a structure-agency lens, this thesis further contributed to avoiding lock-in factors of reasoning by remaining within the borders of the current system when thinking about potential actions. Acknowledging that structures are quite powerful, yet hardly subject to laws of nature, implies that they only persist as long as we reproduce them via our agency. There is "room for maneuver" (Åm, 2019, p. 175) and the possibility that "everything could be different" (Welzer, 2022). While we still need to start from where we are (current system), our actions can still be informed by and oriented towards imagining different futures (future system). In chapters five and six and in several action-oriented outputs presented in chapter eight, I outlined such initial ideas for exploiting this room for maneuver. A very detailed table of possible actions and ways forward according to actor groups can be found in chapter five. The subsequent table in this sub-chapter presents a reduced version of Table 6 from chapter 5.6., presenting only two key actions per actor group, which I suggest starting with.

Table 9: Two key recommendations according to actor group and structural level (adaptation of Table 6 from chapter 5.6.)

Actors	Recommendations according to structural level
Individual team members	(1) *Individual level:* Be aware of the personal investments inherent to ITD integration; reflect upon your motivation and decide consciously if you are willing to make the required investments; display integrative behaviors by engaging your colleagues at eye-level instead of subordinating them into a service role. (2) *Program level:* Treat ITD integration as a core-task (at least temporarily) and assign explicit resources to it as long as you are part of the program.
Program leaders/ integration experts	(1) *Individual level:* Make sure that your team members know that doing ITD integration means diverging from their routines and give concrete, tangible examples of what this might look like; ensure sufficient face-to-face interactions. (2) *Team level:* Assemble your team wisely taking into account factors beyond disciplinary excellence; make sure that there is a critical mass of intrinsically motivated and constructive people in the team driven by a common purpose and willing to share the spotlight.
Directors / Executive boards of institutions	(1) *Individual level:* Contribute to psychological safety by keeping the individual's team members and leaders' backs free for experimenting and engaging in integration properly. (2) *Institutional level:* Revise your current incentive structure and assessment criteria, and analyze to what extent it is encouraging or discouraging ITD integration; implement measures which reward, acknowledge and give visibility to integration efforts.
Funders	(1) *Team level:* Provide tips for team composition during funding calls; assess a proposal team beyond disciplinary excellence. (2) *Program/network level:* Be aware that extrinsic, monetary incentives are not sufficient for making integration work; ask applicants to make explicit what resources they will be able to mobilize to properly engage in ITD integration and what common purpose they pursue with their ITD endeavor; provide explicit funding for integration experts and reimburse travel expenses for face-to-face meetings.
Science policy-makers	(1) *Program/network level:* provide substantial financial support and long time-horizons for research on societally relevant questions. (2) *Socio-political level:* promote collaboration and incentivize public and private actors to engage in ITD integration; support the harmonization of rules between different institutions and/or provide a flexible frame for collaboration to avoid starting from scratch each time.

9.2. Contribution 2: Conceptualization and operationalization of 'integrative leadership' in ITD programs

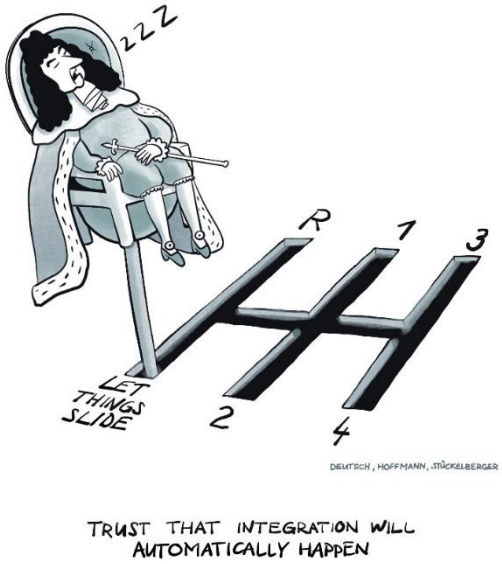

Image 4: © Eawag: Lisa Deutsch & Sabine Hoffmann; Stückelberger Cartoons: Christof Stückelberger, CC BY-NC-ND 4.0

Favorable conditions are important to make integration happen. However, three different projects can be given the same available resources, but can still turn out differently based on how the ITD process has been led (Westberg & Polk, 2016). Although leadership is considered crucial to the success of ITD integration, empirical studies on the real-life experiences and enactment of leadership in ITD practice are growing but scarce (Eigenbrode et al., 2017; Hoffmann, Weber, et al., 2022; Mäkinen, 2018; Palmer, 2018). This thesis contributes to the conceptual understanding and empirical enactment of integrative leadership in ITD initiatives in several aspects.

First, chapters six and seven provided concrete empirical insights about the daily work of leading integration in three large ITD research programs in Switzerland. In chapter six, I derived six core leadership challenges which leaders of ITD programs in Switzerland faced when trying to advance integration in a core team of about 25 individuals and a larger team of over 80 participants, spanning different disciplines, sectors, personalities and hierarchies. These include (1) mastering complexity and ambiguity, (2) advancing decision-making with lateral leadership, (3) ensuring responsibility and accountability, (4) setting program boundaries, (5) selecting suitable projects, and (6) dealing with misconceptions. In chapter seven, I discussed leadership challenges when employing the integrative method 'Theory of Change' within the Eawag program Wings. Those empirical insights are crucial for gaining a better understanding of integrative leadership practice in ITD programs, and make explicit what skill sets (e.g. integration expertise) (Bammer et al., 2020; Hoffmann, Deutsch, et al., 2022), attitude (e.g. lateral leadership), resources (e.g. flexible seed funds), processes (e.g. regular face-to-face meetings) and structures (e.g. co-leadership) can be beneficial for leading integration processes in such diverse and complex settings.

Second, chapters five to seven, but in particular chapter six contributed to the conceptualization of integrative leadership in ITD programs. It argues that leaders of ITD programs are often misconceptualized as having to assume a mere operational and executive, often even passive role although it requires a very proactive leadership role. Chapter six defines integrative leadership in ITD programs as the mobilization of both supportive and creative contributions from team members and leaders during an integration process (Mainemelis et al., 2018). This entails the need to assume a broad range of tasks, namely at least in the areas of (1) coordination and information, (2) facilitation and design, (3) decision-making and accountability, (4) visioning and framing, (5) integration and synthesis, (6) consolidation and dissemination, and (7) reflection and learning (see Figure 4). For the practice of integrative leadership, chapter six argued that efforts need to be mobilized along this continuum continuously (Lyall et al., 2011) because as soon as leaders sit back for a bit longer (see image 4), it is likely that the research process and involved team members will fall back into the business-as-usual mode (see again contribution 1) and their common disciplinary research modes (Mäkinen, 2018, p. 135). Chapters five, six and seven show that understanding leadership positions in ITD projects or programs as primarily an operational role might be a reason why integration is so hard to realize in practice.

Third, this thesis contributes concrete action-oriented knowledge for strengthening integrative leadership in ITD programs. The OECD has suggested that leadership requires "dedicated instead of ad-hoc resources" (OECD 2020, p.27) to meet ITD integration challenges. Chapter six makes concrete suggestions as to what such dedicated resources could look like in terms of assigned working percentages for leaders and the composition of the leadership structure of large ITD initiatives. While there is no one-size-fits all solution to this matter, chapter six suggests assigning at least a 100%, and up to 300% FTEs (full-time equivalent) leadership to ITD programs of a similar size to those of the three case studies Extremes, NCCS-Impacts and Wings discussed. In light of the broad range of tasks required to pursue integrative leadership, a co-leadership structure composed of two individuals with complementary expertise proved useful in the three case study contexts. In addition, chapter six provides concrete strategies for each of the six challenges that proved beneficial from the perspective of the

Figure 4 (in subchapter 6.4.): Portfolio of tasks, responsibilities and contributions of integrative leadership

program leaders required to address them. Thereby, this thesis contributes to supporting current and future program leaders in carrying out their integrative leadership role in ITD programs.

Finally, since chapters five, six and seven all stress the importance of integrative leadership in the future, the question arises as to how future leaders for such ITD programs can be trained. One way forward is to encourage the training of ID and TD integration expertise as early on as this has already been introduced, for instance, at ETH Zurich, where students at undergraduate (Pohl et al., 2020) and graduate level (Vienni-Baptista & Hoffmann, Forthcoming) acquire initial experience in applying integrative methods and leading collaborative processes in a protected setting. However, the question remains how researchers can also be trained on a postgraduate level and within a real-life context. In light of my findings, I suggest that a fruitful way forward could be to include PhDs and PostDocs early on in the leadership of large ITD initiatives. The current academic system and practice often excludes early-career researchers from assuming leadership roles until very late in their career. Given my own positive experience of having been strongly involved in the leadership of the program Wings at Eawag throughout my PhD, I suggest that such an opportunity can be potentially beneficial for both the program itself as well as the early-career researcher. The program might benefit from an early-career perspective (e.g. new impulses, the leadership level would be more tied to the early-career researchers of the program team), while in turn the experience of assuming leadership responsibility contributes to the personal growth and the development of leadership skills of the early-career researcher early on without, however, yet demanding full assumption of responsibility on the part of that researcher. However, the crucial prerequisite for this is that senior researchers assuming official leadership positions include the early-career researchers on an equal footing and without subordinating them in mere service roles.

9.3. Contribution 3: Testing and adapting 'theory of change' as an integrative method for leading ITD programs

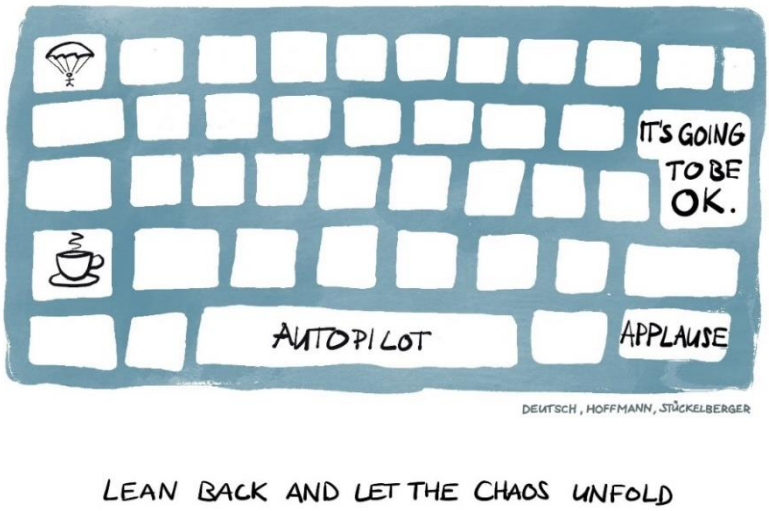

Image 5: © Eawag: Lisa Deutsch & Sabine Hoffmann; Stückelberger Cartoons: Christof Stückelberger, CC BY-NC-ND 4.0

ITD integration and integrative leadership requires both mobilizing supportive and creative contributions (chapter six) at different structural levels (chapter five). This interplay between supportive and creative contributions come together in the question of integrative tools or methods, often also referred to as 'boundary objects' (Star & Griesemer, 1989). Fischer et al. (2024) found that the most effective tools for integration perceived by project participants are those which include a visual component and are able to create a strong group identity. This thesis argued that a method which complies with these two characteristics and can be considered a fruitful boundary object is 'Theory of Change' (ToC). A ToC is a structured mapping of steps, which are assumed to be needed to achieve an overarching vision or goal, coupled with continuous reflection upon how and why change is expected to happen in a specific context (see Figure 8, below) (Belcher et al., 2020; Claus et al., 2023; van Es et al., 2015; Vogel, 2012a). The ToC process can be regarded as an example of where the tasks and roles for assuming integrative leadership are exemplified because it requires both supportive contributions (e.g. coordination, facilitation) as well as more creative intellectual contributions (visioning and framing, integration, reflection and learning). Chapter seven presents insights from developing ToCs within the ITD program Wings and thereby makes several contributions to the how-to of integration on the individual, team and program level (chapter five) via the help of integrative methods:

First, chapter seven shows how ToC can be adapted for the purposes of ITD research programs. Originally used mostly for ex-post evaluation in the community and international development program context, chapter seven provides a detailed description of how ToC can also be used ex-ante to facilitate visioning, planning, monitoring, reflection and learning on the individual and team level, and to advance overall integration on the program level in ITD contexts. The method proved particularly useful for (1)

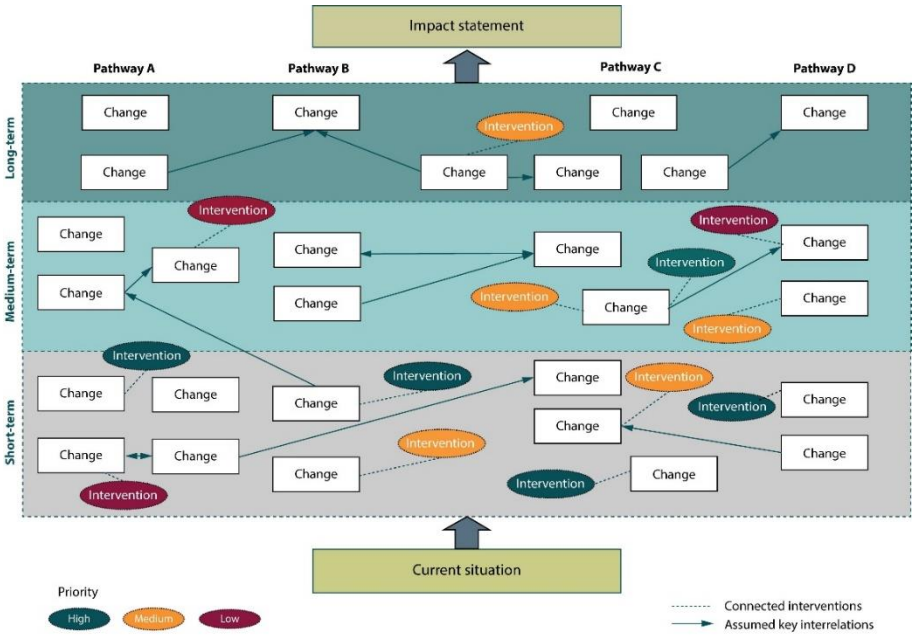

Figure 8 (from subchapter 7.3.2.): Generic ToC at pillar and program level developed within Wings (own elaboration)

jointly creating the bigger picture of what the program tries to achieve, (2) for understanding how the work of the individual team members are interlinked and how they inform or depend on each other, and (3) for brainstorming concrete interventions, hence activities such as workshops or joint synthesis outputs for supporting social change processes in the real word. Overall, the ToC development process proved to be more important than the final output (i.e. final and iterated visualization of ToC) as it allowed the team to overcome overly abstract and unfocused discussions.

Second, by studying the application of the ToC method, chapter seven sheds light on the interlinkages between structure, agency and means. Although developing ToCs suited the program's context and purpose very well, we encountered several challenges in applying the tool which had less to do with the tool itself than with the conditions under which we tried to make it work (chapter five). For instance, ToCs become concrete, meaningful and rigorous when enough time for discussions are invested and when they are organized face-to-face. However, researchers usually have little time available, which makes regular and complete group discussions a challenge. Chapter seven provides several insights into how we improvised to make the method work despite the challenges arising from different structural levels (chapter five). For instance, since senior researchers in particular tend to be very busy, it became imperative to meet with their early-career-researchers on a more regular basis and include their inputs. This in turn, required more leadership resources than initially expected as it meant meeting with a vast number of people on a regular basis and keeping them in the loop to make sure that the program goals and cohesion among its members are upheld (chapter six and seven).

Third, chapter seven contributes concrete lessons learned for future developments of ToCs in ITD programs from an integrative leadership perspective. For instance, utilizing ToCs requires at least one or two motivated individuals, who take the lead and create ownership for the process. It further requires

substantial resources as preparation before meetings, sufficient face-to-face encounters, and processing and integration of the results after meetings are all indispensable to the process. Despite the particular context and structure of the Wings program, the guiding questions and stakeholder analysis developed in line with Vogel (2012a) and Retolaza Eguren (2011) can support other ITD programs in developing ToCs for integration purposes. Guiding questions for facilitating the development of ToCs can be found in chapter seven. In addition, after describing in total five overarching challenges, chapter seven presents in more detail how we reacted to each of them and dealt with the concerns voiced by some program members. An overall lesson from this process is that developing and leading a ToC process can be a valuable opportunity to practice integrative leadership and build up integration expertise step by step (Hoffmann, Deutsch, et al., 2022).

9.4. Limitations and future research

The overall research design, findings and implications of my thesis have a couple of limitations, which I disclose in this chapter while also identifying starting points for future research to address them:

First, all three cases (i.e. the three ITD research initiatives) are located in Switzerland, a high-income industrialized country blessed in terms of a very well-positioned research location and respective funding. Hence, the findings on what has worked well or less well with regards to pursuing integration and the respective challenges reported in chapters five, six and seven need to be seen against this backdrop. At the same time, it is important to note that despite the privileged position of Switzerland, integration remains a challenging undertaking to pursue, which strengthens the finding of this thesis, that overcoming non-integration is not a question of singular factors (e.g. sufficient funding), but requires continuous efforts at several levels and by different actor groups. That said, it would be very valuable to apply the framework from chapter five and the conceptualization of integrative leadership in chapter six in different socio-economic, research and cultural contexts and to examine what differences or commonalities can be found in comparison with the results from the Swiss context. In addition, I want to highlight that the three programs were also located in the German-speaking part of Switzerland. Cultural differences in pursuing integration and dealing with the respective challenges might therefore be found in the French- or Italian-speaking parts of the country. During my research stay (September to December 2023) at the Institute for Environmental Transitions (ITE / Institut de la transition environnementale) at Sorbonne University in Paris, I had the opportunity to contrast the results from the Swiss context as I was able to present my framework and empirical findings from chapter five to researchers there on several occasions. I learned from these encounters that many of the identified structural conditions also resonated with researchers in France.

Contrasting the findings from chapter seven on the employment and adaptation of ‘Theory of Change’ with other contexts would also be beneficial. For instance, Naidoo et al. (2021), Mattos et al. (2022) and

Kok et al. (2022) already referred to our article when studying the employment of ToCs in South Africa, Brazil and a large program in the European Union respectively. While the authors do not necessarily report on the challenges they faced when developing ToCs, an interesting finding across these contexts and synergistic with our article, is that the systemic and visual component of Theories of Change as well as the operationalization of rather vaguely conceived collaborations were identified as key strengths of the method (ibid).

Second, my qualitative research design has mainly relied on self-reports (i.e. interviews, focus groups, reflexive journals). By conducting participant observation, I tried to address this limitation to a certain extent by contrasting what program participants and leaders report versus what they actually do in practice. However, it would be fruitful to study integration processes and respective mechanisms with additional qualitative and potentially quantitative methods not entirely relying on self-reports. Behavioral experiments in collaboration with, for instance, psychologists and behavioral economists could be an interesting avenue for future research in this direction. For instance, findings from chapter five on enabling conditions as well as integrative leadership strategies from chapter six could be explored further by incorporating some of them into an experimental setting. The conceptualization of integration as 'non-routine task' in chapter five can be a good starting point for connecting to behavioral economist experiments in the area of 'non-routine analytical team tasks' (Englmaier et al., 2023). In addition, interview partners were in the majority of cases researchers of the interdisciplinary core teams. I did not interview the practice partners of the larger program team since I focused on the core team (about 25 people per program, including representatives of disciplines and federal offices), which meets on a regular basis. For this reason, the findings relate more to inter- than transdisciplinary integration. Employing the semi-structured interview guideline (see appendix) with practice partners of ITD projects and programs would be a fruitful way forward for addressing the transdisciplinary integration component more strongly and yielding insights for strengthening the science-policy-practice interface. Likewise beneficial would be to examine to what extent and how the integrated outcomes and outputs resulting from the three ITD programs are re-integrated into the respective fields and day-to-day work of the program partners and thereby influence "change into a sustainable direction" in policy, industry and practice as well as academia itself (Polk, 2014, p. 450).

Third, it remains unexplored how implementing the suggested actions in Table 6 in subchapter 5.6. will precisely play out in practice. For this reason, Table 6 is not to be interpreted as a universal recipe, but as a scope of action. It is advisable to discuss and adapt the exact configuration and design of measures from case to case. At the same time, given that the suggested actions were derived from three program and network contexts that still differed in several respects (see again Table 2 in subchapter 4.1. for differences and similarities), I argue that the findings can provide an important action-oriented input for enabling integration in other ITD programs and project contexts as well. Future research could accompany the implementation of the suggested actions and study what effects they have, what unintended consequences might emerge and how such repercussions can be adequately dealt with. This

could happen in a pilot setting, i.e. a research group, department or institute voluntarily implementing these measures, which could then be accompanied by a researcher assuming either only one or a combination of a meta-type and integrator-type role of accompanying research. Theory of Change could be a valuable tool in this regard to document and learn how and why change comes about in these pilot projects. It would also be particularly interesting to learn what reservations and fears implementers of these actions might be confronted with and how this potential 'transition pain' (Bogner et al., 2024) can be addressed. In this regard, the role of emotions and aspirations in academia in general, and in ID and TD integration processes in particular, is also an avenue worth exploring (Cairns et al., 2020) – a topic that often goes "against the grain of an institution that privileges the mind and reason" (Berg & Seeber, 2016, p. 2).

Finally, the topic of power (e.g. the role of hierarchies between junior and senior researchers; the need for lateral leadership in light of lack of formal authority; the negative effect of free riders in ITD teams) is implicitly, but hardly explicitly, addressed in my thesis despite being an ever-present and important factor in ITD integration processes (Fritz & Binder, 2020). All findings could be analyzed and discussed again from the perspective of power by distinguishing multiple forms of power (e.g. 'power over', 'power to', 'power with') and their role in different phases of ID and TD integration processes in research programs as suggested by Fritz and Meinherz (2020). This could potentially yield further interesting implications for program design, integrative leadership and the internal organization of institutions for enabling ID and TD integration in the future.

10. Concluding remarks

ID and TD integration is not pursued for the sake of integration, but can be seen as a response to the inability of a highly differentiated knowledge system in academia to address complex societal questions. Acknowledging this limitation of the current system does not necessarily mean calling for the replacement and dissolution of disciplines as such, but ideally translates into concrete actions which enable and empower ID and TD integration in the long run. Specialization and integration pursue different, yet complementary goals. Integration builds upon specialized expertise and allows new knowledge to emerge, which by definition within a specialized field cannot emerge in the first place as the question would be regarded as 'irrelevant' or considered outside one's own area of interest. Academia will be doing itself no favor if it continues to privilege one (specialization) over the other (integration) in light of the sustainability challenges ahead.

Creating tailwinds to counter current headwinds is therefore crucial for realizing the potential and promise of integration within ID and TD research programs. This thesis aims to contribute to the generation of tailwinds for ITD teams by bridging conceptual and empirical knowledge and generating action-oriented insights on the how-to of integration in three areas: (1) creating more favorable conditions *(structures)*, (2) strengthening integrative leadership *(agency)* and (3) employing integrative methods *(means)*. By embracing and linking these three research foci (*structures*, *agency*, and *means*), this thesis employed a novel integrative approach to the how-to of ID and TD integration itself.

The action-oriented insights gained may also yield important entry points of action for fostering integration on complex problems in other societal sectors. For instance, actors from public administration, industry, policy and practice are equally confronted with the challenge to collaborate across departments, institutions or actor groups in order to successfully develop integrative approaches to contemporary societal challenges such as climate change, sustainability transformations or pandemics. Accompanying the implementation of the identified scopes for action both in academia and beyond would be a fruitful and interesting way forward for both enabling integration in practice, while also studying ID and TD integration processes further in different contexts and thereby advancing this know-how theoretically.

In addition, by studying three different ITD research initiatives in Switzerland and conducting focus group meetings face-to-face with the six leaders of the respective initiatives on a regular basis, this thesis has created a peer-to-peer space for reflection, mutual learning and support for integrative leadership. Given the manifold challenges attached to ID and TD integration and the importance assigned to ITD programs in the future for addressing societally relevant challenges, creating and maintaining such reflective peer-to-peer spaces for fostering integrative leadership will continue to play a crucial role.

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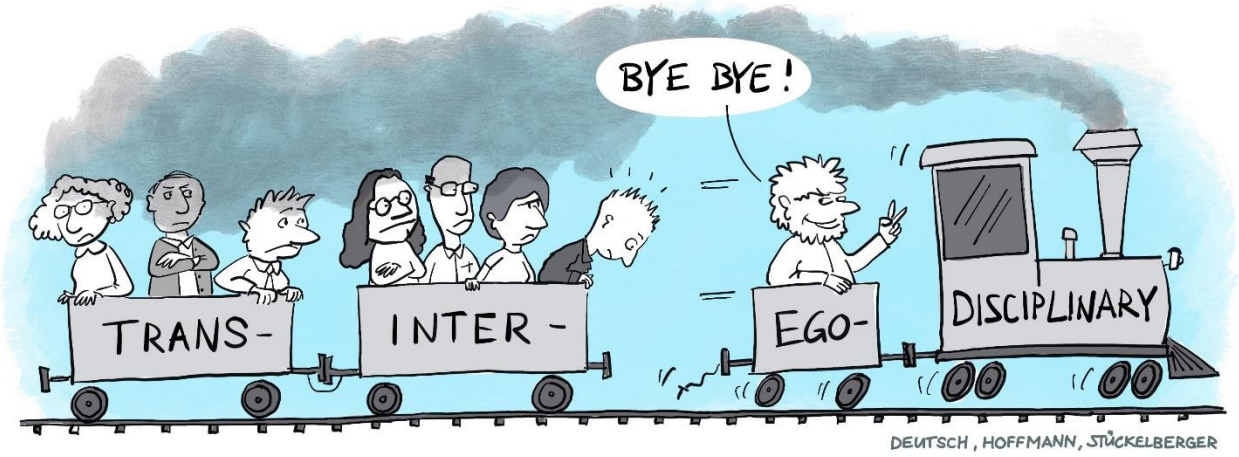
Appendix

A – Cartoons

The cartoons can be can be used via a creative commons license for non-commercial purposes (CC BY-NC-ND 4.0) by stating the following reference: © Eawag: Lisa Deutsch & Sabine Hoffmann; Stückelberger Cartoons: Christof Stückelberger, CC BY-NC-ND 4.0

BECOME A ROLE MODEL OF DESTRUCTIVE BEHAVIOR

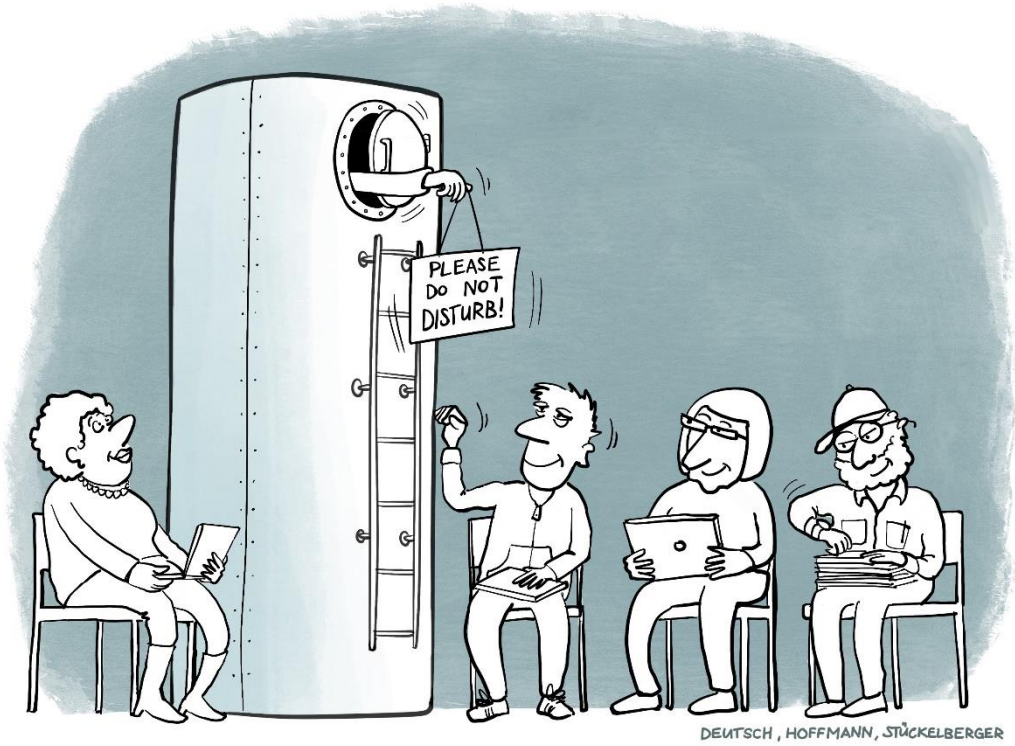


UNCOUPLE YOUR OWN RESEARCH AND MAKE A QUICK GETAWAY

NEVER LET THE DISCUSSION END

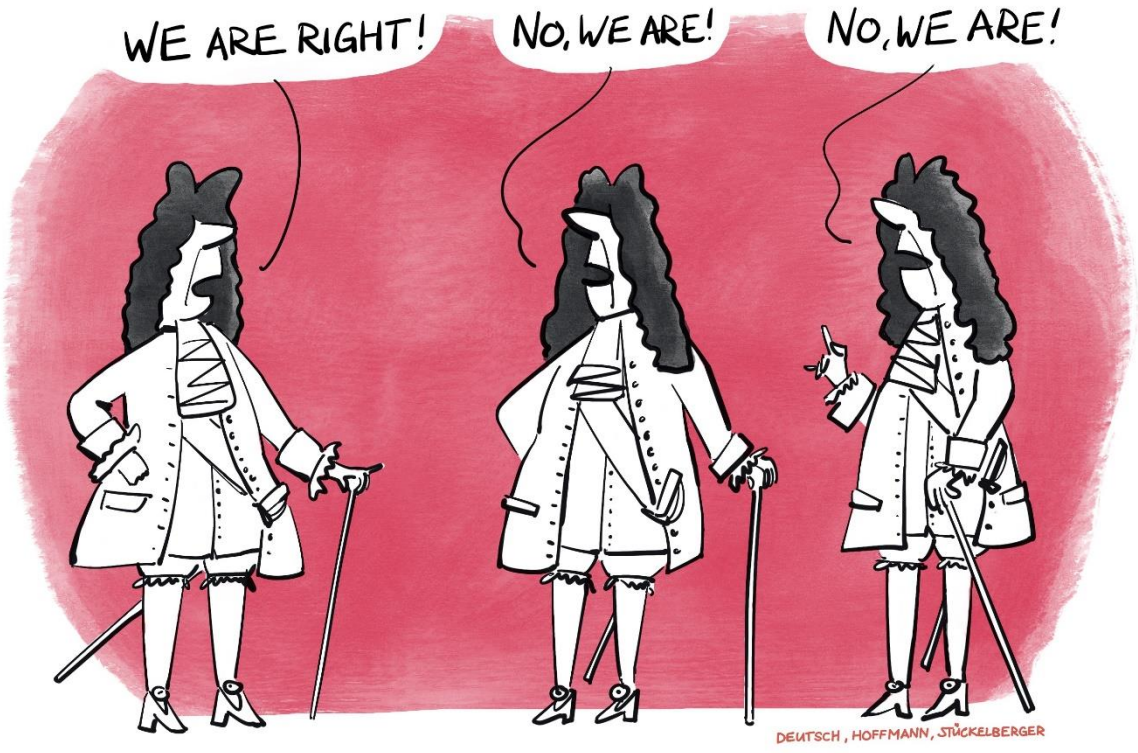
FOCUS ON WHAT IS REALLY IMPORTANT AND LEAVE OUT ALL INTERPERSONAL ASPECTS

FOLLOW BUSINESS-AS-USUAL AND DISMISS OTHER PERSPECTIVES

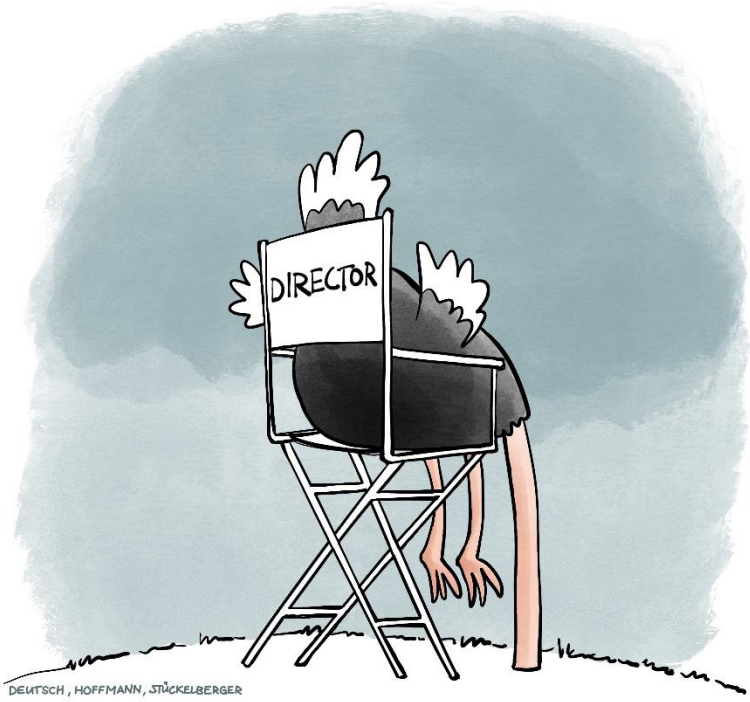


STAY INSIDE YOUR SILO

DENY EARLY CAREER RESEARCHERS ANY COMPETENCIES



NEVER LET GO



BURY YOUR HEAD IN THE SAND FOR A WHILE

HERDING CATS

B – Chapter five

AP1: "*I remember, for example, a discussion ... where [person X] was slightly annoyed by certain statements from [person Y]. So along the lines of "do I have to explain here what [concept Z] is"? But I think that's part of it. You can't assume that others understand what you've been researching in depth for decades." (SM)*

AP2: "*TD is great but it's slow. I have never seen a TD process where things happen fast…and it often needs more energy because you require ample energy to bring people to the same page in the first place and then you can start discussing."* (JM)

AP3: "*In [a previous project] it was the personalities of the main actors of the project, which were quite dominating. Everyone wants to be the best one, everyone wants to rule the project, and that causes a conflict at least... everyone was like, "Yeah, I'm doing the best job, so I decide."* (SM)

AP4: *"I was quite pleasantly surprised with the outcomes that, some of them were a lot cooler than what I had thought, right? So I initially went in thinking, 'I want to validate my ideas', but rather I came out with newer ideas that came out from participants, which was really cool. So, in integration, that's why I'm saying having an open mind is great. I learned it during that workshop that you let people do the thing and more often than not, you might come up with results, which surprise you pleasantly." (JM)*

AP5: *"They were stubborn at the beginning and didn't do what I wanted them to do [sarcastic tone]. And then I understood that I wanted only a little bit from them, but my inclusion of them was, so to speak, zero. I really just wanted them to do service for me. And now I go and I want more from them. So I'm asking for more from them, but they're really a part of it [this time]. Understanding that, that's what I learned for myself here." (SM)*

AP6: *"For the whole group, it's not just the technical expertise that counts...If you know each other and are on friendly terms, you can talk much more openly about problems, and there are no inhibitions or fears that the person takes it the wrong way and that this will immediately be credited negatively." (SM)*

AP7: *"I think you're more likely to work hard on something for someone else if you like them." (JM)*

AP8: *"If you have people who are not constructive, who always want to start from scratch, who always make fundamental oppositions, then it's very difficult." (SM).*

AP9: *"You simply have to be satisfied if you end up with a product that is very beautiful and very successful, where there are 70 names on it and you are one of 70, your name is somewhere on page 34 at the bottom right perhaps. So you have to subordinate yourself in the service of the whole." (SM)*

AP10: *"So much depends on the people... That you don't have too many free riders. You always have them, but that you have a critical mass of people who want to push something forward…who want to make a difference." (L)*

AP11: *"It was a project with different departments involved, so different expertise, let's say. I think if I can be really frank, the people just wrote the project to get the money. They couldn't care less about the project; they just want to have the money to use it for whatever and try to deliver as little as possible about the project."* (SM)

AP12: *"You can operate a program/network like that by simply coming to the meetings and not actually reading anything and thinking, well, it's really none of my business, I was there and I'll leave again. Or you advocate for something and then it becomes very quickly very costly if you want to understand a little bit, what the others are actually doing." (SM)*

AP13: "*For me it has been a constant difficulty. Personally, I have not yet been able to make a contribution, but I think it's actually a great thing and a good format, and I think it would be exciting to do something there, but just knowing that that would mean work, preparation, and so on, I've kind of shied away a bit from doing more...So I don't have a percentage [for working on it], I have to free up somehow."* (SM)

AP14: *"I really think one of the major issues is not that people don't want to be collaborative…people are very enthusiastic actually about the idea of collaborating and a synthesis, but it does tend to get pushed to the back, so you need to make time for it."(JM)*

AP15: "*It's not the top priority. It always gets delayed and it's difficult to find joint appointments… getting these professors to one table is an impossibility. Now I'm actually only doing bilateral work, between the individual groups.*" (SM)

AP16: *"Of course, then you have to make a declaration of renunciation, and that's usually not what people want, is it? So ... Because it's just a pity, so the other topics where I'm committed, they are also very important and then I don't want to shut them down, right?" (SM)*

AP17: *"Whether [integration] takes place or not depends very much on what else is going on; which projects are running, how many papers I am writing and have to hand in. It's like the things you plan to do and then in the end the question is: Is the capacity there or not?"* (SM)

AP18*: "There are just reward systems that don't reward [ITD integration] at all or even punish that. And there are reward systems that encourage that. It would probably still be better for me if I didn't do anything with the others right now... But here at least, that's very much encouraged."* (SM)

AP19: *"When you publish interdisciplinarily, it also costs a lot more time, the journals don't have such a high index or impact factor. The system should actually ensure that an interdisciplinary project or an interdisciplinary paper is acknowledged tenfold… I have the feeling that the disciplinary researchers are simply better able to develop into luminaries in their field. So it's easier to make a career and get international recognition if you work in a disciplinary way." (L)*

AP20: *"Of course, this has to be recognized by the supervisor as something valuable. Then you also get more space and resources, or then it is also okay that you take time for that."* (JM)

AP21: "*We've been working on it for years, but we're only now in the process of putting it out to tender, because a lot of things had to be clarified in terms of procurement law, so much money, resources and staff time is lost without you working on the content.*" (SM)

AP22: "What we all realize, or at least I realize …how difficult it is to get – what I think is a good … absolutely necessary program – on its feet. And how the best collaborations become madly complicated because there are some procurement rules." (SM)

AP23: "*Often, the funds for these [holistic] projects are cut, so you don't have the possibility to include a certain side thread next to the main question… There is simply no room for that …because we don't have enough funds. And then in the end you're back to your silo."* (SM)

AP24: *"These are great things, but they are temporary. Such cross-cutting activities should also be visible in the [institute's] structure…we actually have programmes that temporarily link different departments with each other and the core themes... But [it] would help, if it was institutionalised."* (L)

AP25: "*What also legitimises our activities is the political embedding, that it has been incorporated into a Federal Council resolution and so on. Of course, this also gives us a bit of pressure to act. That is also important. You have to be legitimised somehow as a program/network*." (L)

C – Chapter seven

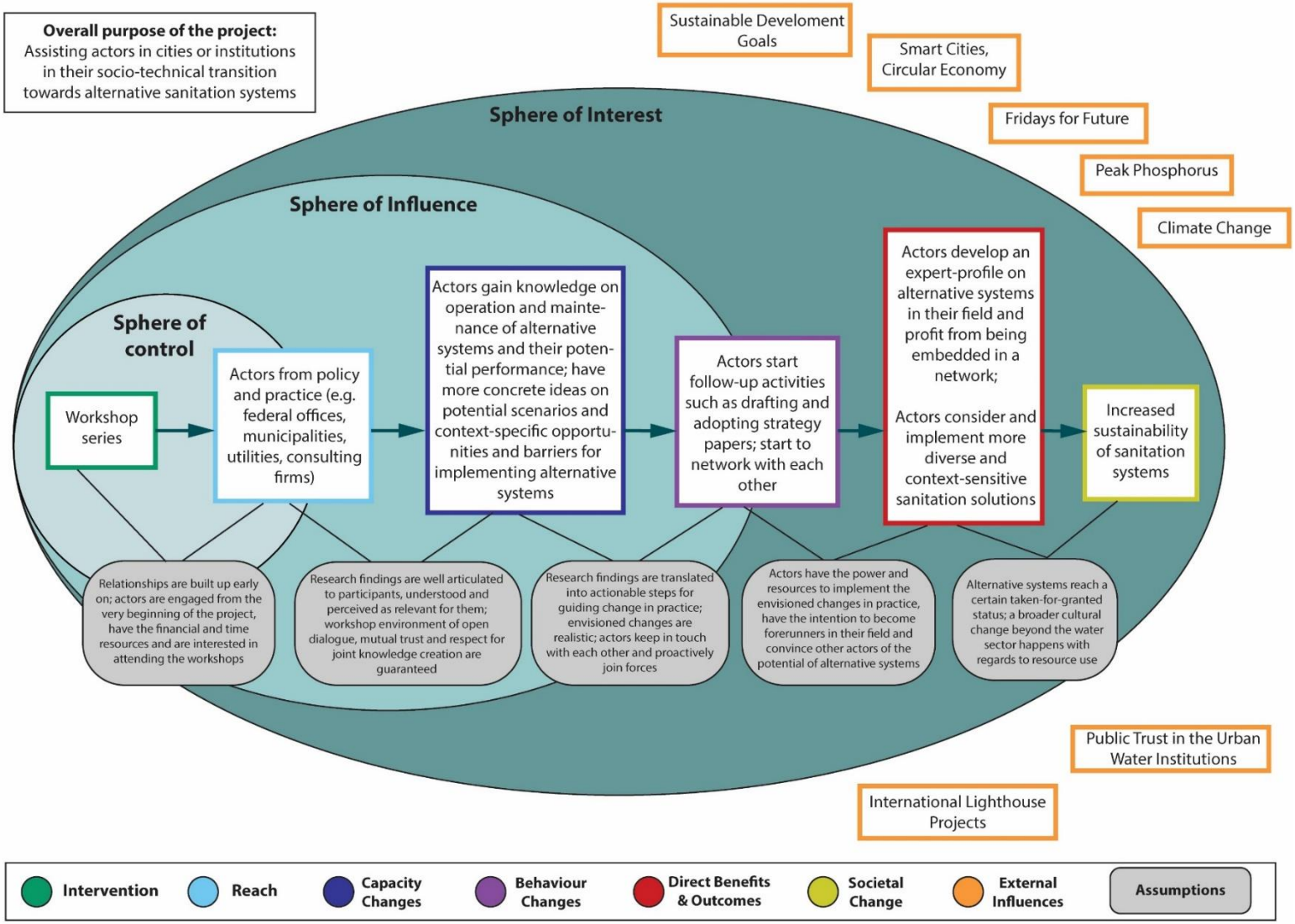


Figure 9: Example of a developed ToC on project level (forecasting) (adapted based on Sustainability Research Effectiveness (2019)and Mayne (2015))

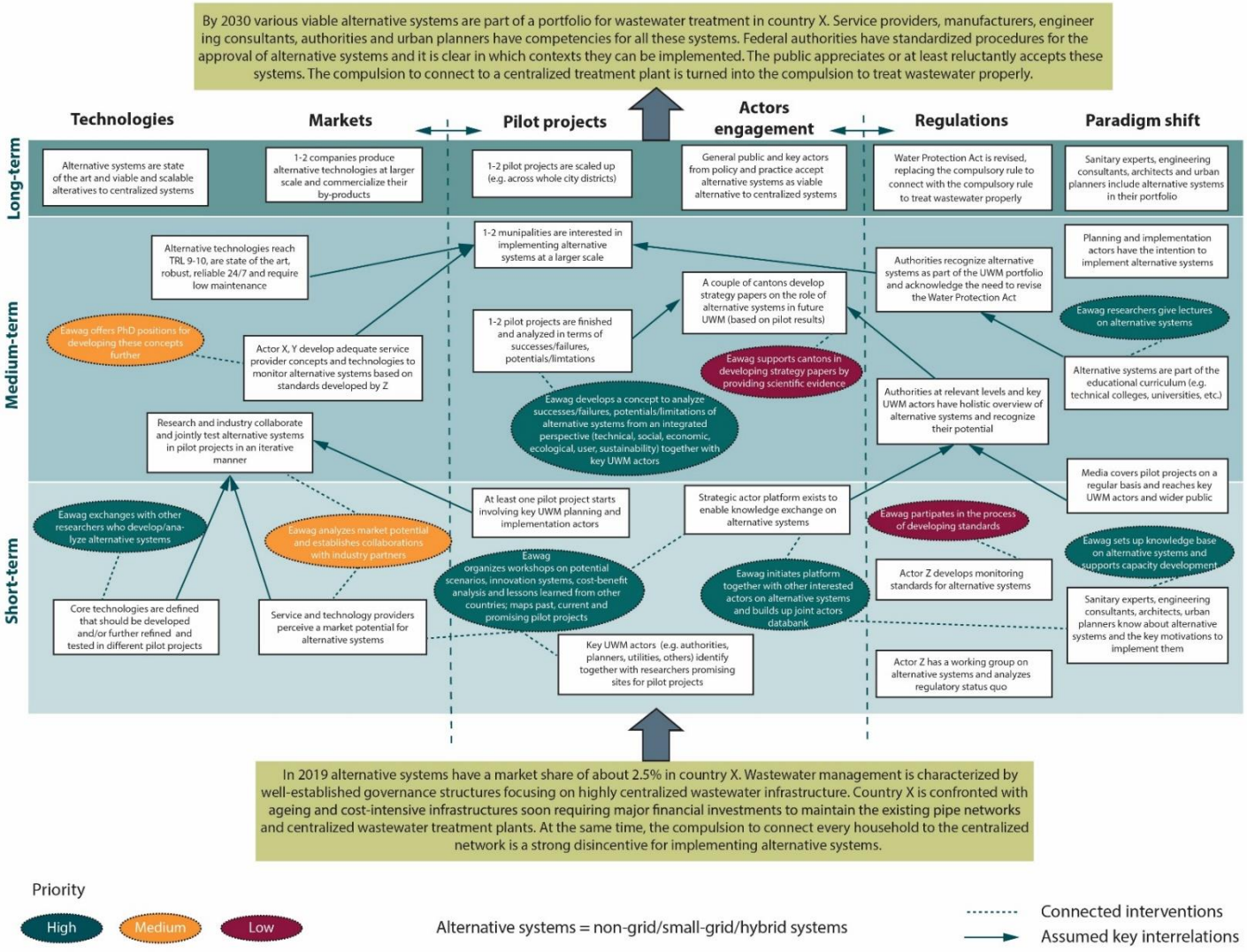


Figure 10: Example of a developed ToC on pillar level (backcasting) within Wings

D – Interview guideline

This interview guideline was developed in line with the research questions and is based on Willis (2019). The subsequent questions were asked to both program members and program leaders. However, program leaders were asked slightly different questions to explore their leadership role more thoroughly in some parts of the interview. These questions are pointed out in brackets.

Opening (10min):

1. How did you come to be part of program/network X? (For leaders: You have been in charge of program/network X since Y. How did you get to this position?)
2. What motivates you to participate in this inter- and transdisciplinary program/network? What do you hope to contribute? (For leaders: What motivates you to lead this program/network? What contribution do you hope to make?)

Integration (20min):

3. In the literature, "integration" is described as a key challenge and core characteristic of inter- and transdisciplinary as well as cross-sectoral collaborations. Often this term appears somewhat fuzzy. What do you understand by integration?
4. Can you give me a concrete example where integration has (not) taken place for you?
5. Example of successful integration: what was decisive for this? What conditions/prerequisites were fulfilled so that integration could take place in this case?
6. Example of unsuccessful integration: what was the decisive factor here? What conditions/prerequisites were not fulfilled in this case?

Integrative Leadership (40min):

7. How do you imagine integration to take place within program/network X?
8. Who is responsible for ensuring that integration takes place in program/network X?
9. What is the role of (the program leaders) X and Y in relation to integration? (Follow-up: i.e. in the end, who leads integration within program/network X?) (For leaders: what is your role as the program/network leader in relation to integration?)
10. What is your role in the program/network? (Follow-up: in relation to integration specifically?) (for leaders: not asked, as already addressed in question 9)
11. What do you need to fulfill this role/contribute to integration? (Follow-up e.g.: skills, attitudes, expertise, conditions, etc.)

12. Can you recall a situation where you were able to fulfill your role in terms of integration in the program/network? Do you have a personal "best practice integration story"? (Follow-up e.g., in which situation did you have the impression that you were able to work very well in an integrative way? What was decisive for you to be able to meet your integrative demands?)

    (For leaders: Can you remember a situation where you were able to live up to your own integrative leadership standards? Do you have a personal "best-practice leadership story"? In which situation did you have the impression that you were a good integrative leader? What was decisive for you to be able to live up to your integrative leadership principles?)

13. Do you also have a personal "integration horror story" where you could not fulfill your role in terms of integration in the program/network? What was the decisive factor here? What prevented you from working in an integrative way?

    (For leaders: Do you also have a personal "leadership horror story"? What was the decisive factor here? What prevented you from leading in an integrative way?)

14. If we now consider your own horror story and the best practice integration story together, as well as the circumstances under which they took place, what conclusions do you draw with regard to the future of your integrative work in the program/network and for integration in general in the program/network? (For leaders: What conclusions do you draw with regard to your own integrative leadership practice in the future?)

Outlook (10min):

16. What challenges do you anticipate in the program/network in the coming weeks and months and how do you think they should be addressed? What contribution can you make to address these challenges?

17. Looking back on the interview, is there anything else you would like to add? Is there any other aspect that I haven't addressed so far, but would be important to discuss?

E – Ethical approval

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

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Zurich, 01 March 2022 ZS

EK 2022-N-15: Lead ITD! – Exploring integrative leadership in inter- and transdisciplinary research

Dear Ms Hoffmann,

Your above proposal, submitted on 20 January 2022, has been reviewed by the following members of the ETH Zurich Ethics Commission:

Prof. Dr. Lutz Wingert, Präsident	Professur für Philosophie
Prof. Dr. Isabel Günther	Professur für Entwicklungsökonomie
Dr. Kai-Uwe Schmitt	AGU Zürich

Based on the Commission's recommendation, the Vice President for Research of ETH Zurich has come to the following decision:

☒ **Approval without reservation** ☐ Approval with reservation ☐ Revise and reply
☐ Revise and resubmit ☐ Rejection ☐ Not evaluated

Final provisions

You are required to inform the Ethics Commission immediately on any of the following occasions:

a) if an event occurred that affects the integrity of the participants or the continuation of the research project;

b) if you wish to make changes to the research protocol or to extend the project; or

c) if the study is prematurely terminated.

Kind regards,

Prof. Detlef Günther
Vice President for Research

Prof. Lutz Wingert
Chair ETH Zurich Ethics Commission

1 / 1