

Principles for Leading, Learning, and Synthesizing in Inter- and Transdisciplinary Research

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Synthesizing heterogeneous findings from different scientific disciplines, thematic fields, and professional sectors is considered to be a critical component of inter- and transdisciplinary research endeavors. However, little is known about the complex interplay between synthesizing heterogeneous findings, leading creative synthesis, and learning about leading and synthesizing. In the present article, we therefore focus on the key interactions between leading and synthesizing, between synthesizing and learning, and between learning and leading in inter- and transdisciplinary contexts and compile a set of 21 principles that guide the interactions between these components. We use these principles to reflect ex post on the benefits and challenges we encountered in developing a nationwide monitoring program for river restoration in Switzerland and draw lessons learned for future inter- and transdisciplinary research endeavors. We conclude that learning and synthesizing do not happen on their own but need to be designed as intentional and purposeful processes.

Keywords: creative synthesis, interaction, collaboration, river restoration, lessons learned

In a rapidly changing globalized world with finite natural and often limited socioeconomic resources, environmental management on the local to regional scale becomes increasingly challenging (Allan and Stankey 2007). Challenges arise because the systems to be managed are usually characterized by a high level of complexity and uncertainty in social, economic, technical, and political realms (Chapin et al. 2009). Given their complexity and uncertainty, such challenges can typically not be addressed by traditional disciplinary or sectoral approaches or by single individuals (Hämäläinen et al. 2014). Rather, there is a need for collaborative efforts aimed at combining a wide range of perspectives not only from different disciplines and thematic fields (*interdisciplinarity*) but also from different professional sectors, such as research, policy, and practice (*transdisciplinarity*). Such a “constructive combination—or *integration*—of perspectives” (O’Rourke et al. 2016, p. 62, emphasis was in the original) allows the development of a more comprehensive understanding of complex and uncertain environmental problems and the generation of promising policy- or practice-oriented solutions (Allan and Stankey 2007, Pohl and Hirsch Hadorn 2007).

Dealing with complex and uncertain problems in such collaborative inter- and transdisciplinary efforts implies not only identifying important contributions from multiple and often diverse stakeholders but also processing, analyzing,

integrating, prioritizing, and, ultimately, synthesizing these contributions (Hoffmann et al. 2017a) with a view to generating new knowledge that is more than the sum of the different parts being brought together (Carpenter et al. 2009). It also implies mutual learning among stakeholders from different disciplines, fields, or sectors while thoroughly examining the various contributions and critically reflecting on their underlying assumptions (Mezirow 1997). Ultimately, inter- and transdisciplinary research also implies leading such collaborative synthesis efforts (i.e., setting and enforcing the boundary conditions and triggering, enabling, and sustaining such efforts over time with a view to achieving the specific purposes of creative synthesis). Such purposes include enhancing scientific understanding of complex and uncertain problems (Hampton and Parker 2011, Bammer et al. 2020); increasing the generality, transferability, and applicability of scientific results (Hackett et al. 2008, Hampton and Parker 2011, Lynch et al. 2015); generating policy- or practice-oriented solutions (Carpenter et al. 2009, Bammer et al. 2020); producing targeted synthesis products (Hoffmann et al. 2017a); drawing lessons from particular cases and contexts (Krohn 2008, Adler et al. 2017); and opening new research areas (Hampton and Parker 2011).

We consider the processes of synthesizing (Carpenter et al. 2009, Sidlauskas et al. 2010, Hampton and Parker

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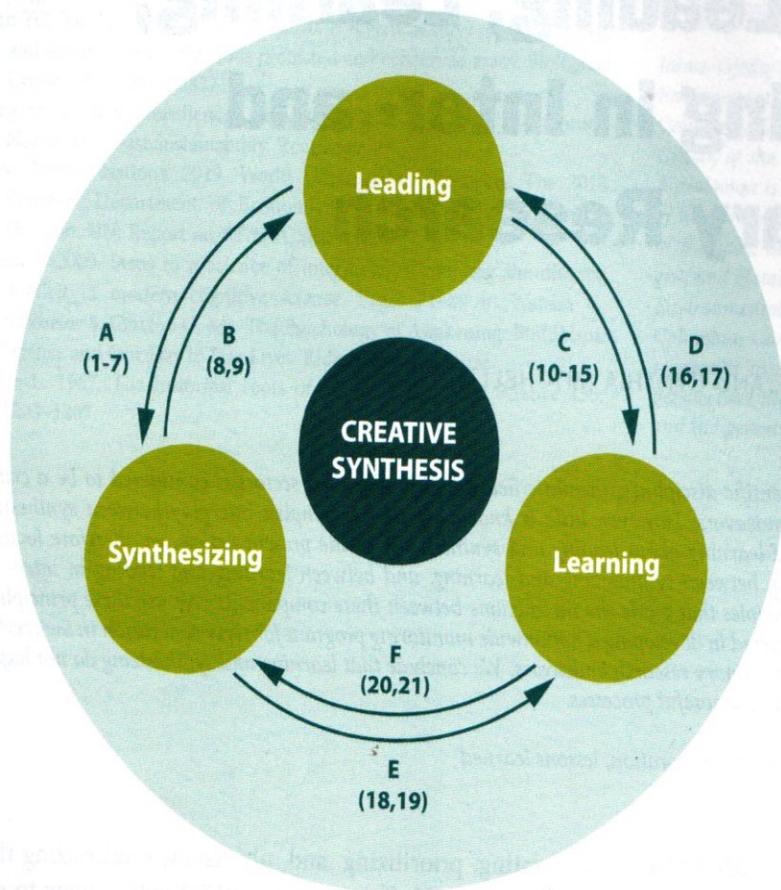


Figure 1. Three essential components (boxes) of creative synthesis (Harvey et al. 2018)—leading, learning, and synthesizing—and their key interactions in inter- and transdisciplinary research (arrows). The arrows indicate the directionalities of interactions; the labels refer to the respective interactions (capitals) and the principles guiding them (numbers).

2011, Hackett and Parker 2012, Lynch et al. 2015, Specht et al. 2015b, Hoffmann et al. 2017a, 2017b, Wyborn et al. 2018), leading (Gray 2008, Eigenbrode et al. 2017, Uhl-Bien and Arena 2017, Mäkinen 2020) and learning (Pennington et al. 2013, Freeth and Caniglia 2019) to be essential components of such collaborative efforts (cf. figure 1). Although all three components are widely discussed in the literature, little attention has been given to the critical connections between them (Allan and Stankey 2007) and therefore to the key interactions between leading and synthesizing, between synthesizing and learning, and between learning and leading in inter- and transdisciplinary contexts.

In the present article, we will first disentangle the three components leading, learning, and synthesizing. We will then focus on the specific interactions between these components, as is illustrated in figure 1, and compile a set of principles that guide such interactions in inter- and transdisciplinary contexts. The principles are derived from the recent literature on inter- and transdisciplinary research, science and technology studies, the science of team science,

and organizational research, as well as from our own and others' practical experiences in leading, learning, and synthesizing in inter- and transdisciplinary contexts. We will deploy these principles to critically reflect ex post on the benefits and challenges we encountered in developing a nationwide monitoring program for river restoration in Switzerland within the Program for Monitoring and Evaluation (ProME) development project. Finally, we will draw some tentative lessons learned for future projects or programs aiming at generating new knowledge beyond the boundaries of any scientific discipline, thematic field, or professional sector.

Our article is inspired by recent calls for a more iterative and reflexive second order science approach (Fazey et al. 2018, Norström et al. 2020, Wittmayer et al. 2021). Such an approach “shifts focus away from studying a system as if looking in from the outside to conducting research as if from within. This includes reflexively examining one's own role in the way a system is reproduced” (Fazey et al. 2020, p. 6). Following such an approach, the two present lead authors assumed a double role—that is, in leading creative synthesis in diverse inter- and transdisciplinary contexts, including the ProME development project, and in critically reflecting on their own role in the way

creative synthesis was led. We both started our individual reflections from complementary angles: one of us—a scholar on inter- and transdisciplinary research—studied conceptual aspects of leading, learning, and synthesizing in theory and applied such theoretical knowledge to lead collaborative synthesis efforts in practice. The other author—a scholar on river ecology and restoration—led such synthesis efforts in practice, including within the ProME development project, and used such practical knowledge to develop new methodological and conceptual approaches to leading, learning, and synthesizing. Over a period of 2 years, we both linked and related our scientific and experiential knowledge on leading, learning, and synthesizing in inter- and transdisciplinary contexts with a view to articulating our conceptual and empirical insights. The present article represents the results of such iterative and reflexive process, which included many rounds of individual reflections, collective discussions and continuous adaptations. It is meant to contribute to bridging the perceived divide between the theory and practice of inter- and transdisciplinary research (Huutoniemi et al. 2010).

Conceptualizing leading, learning, and synthesizing

In the following sections, we will unravel the three components we consider essential for any collaborative inter- and transdisciplinary synthesis effort: leading, learning, and synthesizing.

Synthesizing. As its core, synthesis as a creative process generates new knowledge in which the whole is greater than the sum of its parts (Carpenter et al. 2009). This process takes stock of what we know and creates new knowledge by combining disparate elements (e.g., questions, concepts, theories, methodologies, results, and data) and perspectives from one or more scientific disciplines, thematic fields, and professional sectors (Carpenter et al. 2009, Sidlauskas et al. 2010, Hackett and Parker 2012, Lynch et al. 2015) and by establishing previously unrecognized connections among them (Jahn et al. 2012, Specht et al. 2015a, Hoffmann et al. 2017a). Often, targeted synthesis products (e.g., reports, videos, factsheets) tailored to the specific knowledge needs of intended audiences are developed in the process (Hoffmann et al. 2017a). Such products are designed to summarize the new knowledge so that intended audiences can make effective use of it (Defila et al. 2006, Pohl and Hirsch Hadorn 2007, Lang et al. 2012). Synthesis is therefore regarded in the present article as a type of integration.

Integrating the diversity of elements and perspectives from different disciplines, fields, and sectors while recognizing new connections and synthesizing newly generated knowledge into final targeted products takes a significant amount of time and effort (O'Rourke et al. 2019). It also requires an often underestimated commitment among all group members to recognize, appreciate, understand, engage in, and build on the diversity of elements and perspectives to generate such knowledge (Harvey et al. 2018, Mäkinen 2020). If this commitment is lacking, highly diverse groups may struggle to attain targeted synthesis products (Harvey 2014). Therefore, understanding the processes through which heterogeneous elements and perspectives are constructively combined and ultimately synthesized (Harvey et al. 2018), as well as designing such processes as intentional and purposeful collaborative efforts (Pennington et al. 2021), is critical for achieving targeted products.

Leading. As in any scientific endeavor, leaders play a crucial role in setting and enforcing the boundary conditions for such collaborative efforts and in triggering, enabling, and sustaining such efforts over time to attain targeted synthesis products (Harvey et al. 2018). Harvey and colleagues (2018) recently developed a model of leading for creative synthesis. According to that model, integrative leaders are required to effectively marshal necessary resources to support synthesis and to continuously manage complexity, uncertainty, and ambiguity by allowing a group's members to diverge and contribute their unique and diverse perspectives while also helping them periodically converge and move their perspectives (including their own) forward in a common direction.

To do so, they need to sustain and protect adaptive spaces that allow diverse perspectives to conflict (i.e., engaging tension) and connect (i.e., bridging differences and creating links) in ways that enable the emergence of new knowledge (Uhl-Bien and Arena 2018). Finally, they are required to constantly expose such new knowledge to external feedback (Harvey et al. 2018).

Leading for creative synthesis may imply a combination of complementary leadership styles (Harvey et al. 2018). For instance, inspiring group members to generate new knowledge by establishing critical connections between previously unrelated perspectives, as well as to challenge existing perspectives and their underlying assumptions, may require transformational leadership (Harvey et al. 2018). Creating a positive environment that promotes creativity, productivity, and serendipity (Hampton and Parker 2011, Specht et al. 2015a), in contrast, may imply supportive leadership (Kandiko 2012, Harvey et al. 2018). Harvey and colleagues (2018) therefore concluded that leading for creative synthesis “requires contextual leadership, which allows leaders to engage in different ends of the spectrum” (p. 201), depending on the particular stage and the specific context of the synthesis process (cf. Oc 2018). The demanding set of leadership capabilities (Salazar et al. 2019) and leadership styles (cf. Anderson and Sun 2017) suggests that a small number of leaders, sharing or distributing leadership across their groups' members, may be more effective than a single individual in leading for creative synthesis (Krainer and Lerchster 2015, Hoffmann et al. 2017a).

Learning. Learning among a group's members is considered to be crucial for generating new knowledge and effectively posing and solving complex problems (Pennington et al. 2013, Pennington et al. 2021). The group members (ideally) learn together while critically examining different perspectives—that is, by questioning their own perspectives (in light of the perspectives of others), reflecting on their own assumptions, and readjusting their own sets of theories, concepts, and methods to develop a shared theoretical, conceptual, or methodological framework (Tress et al. 2005, Beland Lindahl and Westholm 2014). Mezirow (1997) referred to this process as *transformative learning*—that is, as “the process of effecting change in a *frame of reference*” (Mezirow 1997, p. 5; the emphasis was in the original) and creating a new frame of reference that is more inclusive, permeable, and integrative (Sterling 2010, Pennington et al. 2021).

A group's members engaging in creative synthesis often experience a “disorienting dilemma” (Pennington 2013, p. 570) while examining and combining heterogeneous elements and perspectives from different disciplines, fields, and sectors. Such disorientation results from the deluge of new theories, concepts, and methods they are confronted with, as well as from a range of new collaborations they are engaged in to generate targeted synthesis products (Pennington et al. 2021). If appropriately addressed, disorientation can create prospects for learning about synthesizing and leading when

group members draw on their direct experiences (Freeth and Caniglia 2019) and reflect, think, and act (Kolb et al. 2014) on the uncomfortable cognitive, social, and emotional (Boix Mansilla et al. 2015) challenges they face in their collaborative efforts. The group members therefore learn to lead or synthesize by actively engaging in leading or synthesizing and critically reflecting on challenging experiences with a view to changing how they lead or synthesize (Kolb et al. 2014, Freeth and Caniglia 2019).

Principles that guide key interactions between leading, learning, and synthesizing

In the present section, we present a set of 21 principles that will support leaders and teams in successfully leading and engaging in creative synthesis. Drawing on the conceptual insights above, we will focus on principles that guide the key interactions between leading and synthesizing, synthesizing and learning, and learning and leading, as is illustrated in figure 1. The principles are systematized within an ideal-typical inter- and transdisciplinary research process (Jahn et al. 2012, Lang et al. 2012, Hoffmann et al. 2019, Pohl et al. 2021). Research projects or programs run through such a process in different order and progressively extend their boundaries into the realms of research, policy and practice (Hoffmann et al. 2019). Although the reality of an inter- and transdisciplinary research process is messy and complex (Pohl et al. 2021), the ideal-typical characterization of such a research process helps to structure the set of principles within such a process. In reality, some principles are not neatly sequential (e.g., provide a positive environment), whereas others cut across two or all key interactions (e.g., build diverse groups, manage time and effort, manage power relations and conflicts). Moreover, interactions between leading and synthesizing, between synthesizing and learning, and between learning and leading are not commutative—that is, leading for learning, for instance, is not the same as learning about leading. We take these directionalities into account and assign principles to the corresponding direction of interaction, as is illustrated in figure 1 and discussed below. We further differentiate principles that are especially directed to leaders from those directed to both leaders and teams.

The principles emerged over a period of 2 years in an iterative process: An initial set of principles was derived from the recent literature and then triangulated with our own experiences and the experiences of others in leading creative synthesis in diverse inter- and transdisciplinary contexts. The process involved many rounds of individual reflections, collective discussions, and continuous adaptations and led to the 21 principles outlined below. The main purpose of the principles is to describe what is needed to lead and engage in collaborative synthesis rather than prescribe how to apply these principles in a given context (cf. Fazey et al. 2018). We suggest that working toward applying these principles by both leaders and teams will add value to inter- and transdisciplinary

projects and programs and unfold their potential for creative synthesis.

In the following, we will summarize principles that guide interactions between leading and synthesizing. The first set of principles (principle 1–7) relate to leading for synthesizing (cf. arrow A in figure 1): design synthesis process, form diverse group, forge social bonds, connect different perspectives, create boundary objects, and assess and disseminate new knowledge. The second set of principles (principle 8–9) relate to the inverse direction—namely synthesizing for leading: provide direction and clarify expectations (cf. arrow B in figure 1).

Principle 1: Design synthesis process. Design synthesis as a purposeful process that starts concurrently with all other research activities, involving an initial phasing-in stage of conceptualization, an intermediate stage of constructive combination and critical connection of previously unrelated elements and perspectives, and a final phasing-out stage of consolidation, validation, and dissemination of targeted synthesis products (Hoffmann et al. 2017a). This principle is especially directed to leaders.

Principle 2: Form a diverse group. Compile a group of experts from different scientific disciplines, thematic fields, and professional sectors willing to invest substantial time and effort to achieve creative synthesis (Hackett and Parker 2012). Ensure diversity in group composition in terms of expertise with an underlying thread of common interest through which to connect their diverse perspectives (Harvey et al. 2018, Deutsch et al. 2021). Strive for cohesiveness and consistency in group composition over time (Hampton and Parker 2011). This principle is especially directed to leaders.

Principle 3: Forge robust social bonds. Facilitate socioemotional relations among highly diverse group members and craft a productive group culture and identity (Hackett and Parker 2012). Engage in formal and informal interactions between group members (Carpenter et al. 2009, Mäkinen 2020) in order to bridge disciplinary, sectoral, and cultural divides (Pohl 2008, Lynch et al. 2015) inherent in synthesis groups (Hackett and Parker 2012), which can otherwise create cognitive, social, and emotional barriers (Boix Mansilla et al. 2015) and therefore obstruct creative synthesis (Hampton and Parker 2011, Hackett and Parker 2012). This principle is especially directed to leaders.

Principle 4: Connect diverse perspectives. Collect and screen disparate elements (e.g., questions, concepts, theories, methodologies, results, and data) and diverse perspectives from different disciplines, fields, and sectors (Hoffmann et al. 2017a). Encourage members to contribute their unique perspectives (Harvey et al. 2018, Bammer et al. 2020). Move divergent perspectives forward in a common collective direction (Harvey et al. 2018) while maintaining the “flexibility to capitalize on the serendipitous, potentially

transformative ideas that emerge” (Hackett et al. 2008, Hampton et al. 2011, p. 908). Identify relevant gaps and overlaps (Deutsch et al. 2021). Build on similarities within diverse perspectives (Harvey et al. 2018, Bammer et al. 2020) and determine critical connections and potential synergies (Deutsch et al. 2021).

Principle 5: Create boundary objects. Rather than discussing divergent perspectives in detail (Weber et al. 2017), make such perspectives concrete and tangible, and realize them in some physical form such as drawings, sketches, documents, lists, or “material artefacts” (Pennington et al. 2012), that is, externalized representations that facilitate exchange across perspectives (Star and Griesemer 1989). Analyze and prioritize diverse perspectives to be temporarily integrated or excluded in a transparent way (Hampton and Parker 2011) in order to achieve a temporary synthesis (Harvey et al. 2018) taking into consideration that not all perspectives can be reconciled (Cronin and Weingart 2007), particularly at a given point in time.

Principle 6: Assess new knowledge. Assess new knowledge with regard to its relevance and usefulness for posing and solving complex and uncertain problems (Hoffmann et al. 2019). Expose new knowledge to external feedback (Harvey et al. 2018) and connect the synthesis group with intended target groups not involved in the synthesis process for the purposes of identifying and selecting knowledge deemed to be relevant and useful from their perspective and of scrutinizing the potentials and limits of that knowledge for both science and practice at large (Hoffmann et al. 2019).

Principle 7: Disseminate new knowledge. Adapt and tailor new knowledge (deemed relevant and useful) to the particular knowledge needs of the intended target audiences (Lang et al. 2012, Hoffmann et al. 2019). Develop strategies to disseminate that knowledge at a time that suits the agenda of such audiences (Rich and Oh 1993) through, for instance, social media, meetings, workshops, and seminars or forums, as well as via contributions to journals, networks, or conferences (Hoffmann et al. 2019).

Principle 8: Provide common direction. Develop a shared vision and define the specific purpose of creative synthesis. Express such a vision “as tangible products rather than as lofty ideals” (Mumford et al. 2002, Salazar et al. 2019) and keep that vision shared across the group. Provide common direction to achieve that vision—that is, facilitate shared goals (Anderson and Sun 2017); specify and prioritize short-, medium-, and long-term goals (Deutsch et al. 2021); and define and sequence different stages to achieve such goals (Hoffmann et al. 2017a, Salazar et al. 2019). This principle is especially directed to leaders.

Principle 9: Establish clear expectations. Clarify expectations regarding targeted products resulting from the synthesis

process (National Academies of Sciences, Engineering, and Medicine 2018) and the specific contributions of each group member to such products. Determine who contributes what, at which stage, for which purpose, and supported by which methods and procedures (Hoffmann et al. 2017b). Establish clear expectations regarding sharing, processing, managing, analyzing, and synthesizing available data, intellectual property, authorship, and other ethical considerations (Hampton and Parker 2011).

In the following we will summarize principles that guide interactions between leading and learning. The first set of principles (principles 10-15) relate to leading for learning (cf. arrow C in figure 1): design learning process, establish a positive environment, facilitate transformative learning, and manage time, effort, power relations and conflicts. The second set of principles (principle 16-17) relate to the inversion direction—namely, learning about leading: promote experiential learning and support academic careers (cf. arrow D in figure 1).

Principle 10: Design learning process. Design learning about creative synthesis as a purposeful process of constructive combination and critical connection of unrelated perspectives and selective generation of targeted products, involving iteration, reflection, and continuous adaptation among all group members (National Academies of Sciences, Engineering, and Medicine 2018). Highlight and visualize the specific purposes of creative synthesis, foster explicit reflection on such purpose, the group’s shared goals as well as the group’s progress toward achieving such goals (Salazar et al. 2019). Ensure, if necessary, adaptation in the ongoing process (Hoffmann 2016). This principle is especially directed to leaders.

Principle 11: Establish a positive environment. Promote an environment of solidarity, safety, trust, and commitment within the group and with respect to its ideas (Hackett and Parker 2012, Freeth and Caniglia 2019)—that is, an environment in which group members are empathetic and open to other perspectives and committed to listening to each other (Mezirow 1997, Bammer et al. 2020)—are motivated to contribute and draw on one another’s contributions (Harvey et al. 2018), feel effectively heard, appropriately considered, and adequately credited for their contributions (Berger 2019). This principle is especially directed to leaders.

Principle 12: Facilitate transformative learning. Enable transformative learning through structured dialogue (Eigenbrode et al. 2007, McDonald et al. 2009). Assist group member to become more aware and critically reflective in assessing their own and others’ assumptions governing their own and others’ beliefs and values (Mezirow 1997, Deutsch et al. 2021), recognizing individual and collective frames of reference and imagining alternative frames that are more inclusive, permeable, and integrative (Mezirow 1997, Pennington et al.

2021). Encourage group members to diverge (Harvey et al. 2018) and to negotiate their own beliefs and values rather than uncritically act on those of others (Mezirow 1997). This principle is especially directed to leaders.

Principle 13: Manage time and effort. Manage time and effort in working together (Mäkinen 2020) by creating a rhythm and pace that enables a balance between process- and output-oriented tasks (Freeth and Caniglia 2019). Give group members adequate time to engage in such tasks and ensure that they spend enough of that time working together to identify and build on similarities across divergent perspectives (Harvey et al. 2018) and enable emergence of new knowledge (Uhl-Bien and Arena 2018). This principle is especially directed to leaders.

Principle 14: Manage power relations. Make conscious efforts to manage power relations among different types of expertise (e.g., natural sciences versus social sciences or quantitative versus qualitative approaches; MacMynowski 2007, Hackett and Parker 2012). Explicate differences between assumptions governing different types of expertise and the power associated with them (MacMynowski 2007)—that is, give equal credence to each perspective in order to avoid that one perspective dominates another (something that can be very difficult to achieve because experts usually favor the validity of their own perspectives; Lynch et al. 2015). This principle is especially directed to leaders.

Principle 15: Manage conflicts. Make conscious efforts to explicate underlying issues and concerns that undermine the creative process (MacMynowski 2007, Freeth and Caniglia 2019). Grasp the nature of such issues and concerns as well as the possible outcomes of ending the conflicts versus encouraging them (Harvey et al. 2018) while directing them to an open discussion that has the potential to increase the constructive combination of divergent perspectives (Salazar et al. 2012). This principle is especially directed to leaders.

Principle 16: Promote experiential learning. Support group members in actively engaging in leading collaborative synthesis and in critically reflecting and acting on their experiences, their successes, and their failures (Freeth and Caniglia 2019). Encourage members to learn through reflective writing (Boud 2001, Pennington et al. 2021) by providing them with guiding questions to reflect on the—cognitive, social, and emotional (Boix Mansilla et al. 2015, Pohl et al. 2021)—challenges they experience in leading and engaging in collaborative synthesis as well as on potential strategies to address such challenges (Deutsch and Hoffmann 2021, Hoffmann et al. 2022). This principle is especially directed to leaders.

Principle 17: Support academic careers. Make conscious efforts to achieve a balance between producing scientific outputs

that effectively advance individual careers on the basis of traditional disciplinary standards on one hand and leading creative synthesis that significantly increases collaborative propensity and visibility and positively affects academic careers in the long term on the other (Hackett 2005, Parker 2010, Hoffmann et al. 2022). Manage the tension between the need to produce scientifically and the need to work creatively (Kandiko 2012, Uhl-Bien and Arena 2018)—all the more because group members are likely to perceive that traditional disciplinary research appears to be a faster path to productivity than inter- and transdisciplinary research (Mäkinen 2020) or collaborative synthesis (Hampton and Parker 2011).

In the following, we present principles that guide interactions between learning and synthesizing. The first two principles (principle 18–19) relate to synthesizing for learning (cf. arrow E in figure 1): provide support and draw lessons learned. The second two principles (principle 20–21) relate to the inverse direction—namely, learning about synthesizing (cf. arrow F in figure 1): recruit integrative leaders and teach collaborative synthesis.

Principle 18: Provide support. Provide technological and methodological support is crucial to manage, process, share, analyze, interpret, and synthesize a wide range of diverse data sets (Lynch et al. 2015, Specht et al. 2015b). Support long-term data storage in common databases to allow later cross-case and cross-context analysis (Weber et al. 2017). Use technological resources (e.g., videoconferencing tools, project management tools) to strengthen communication and coordination within the group (Hall and O'Rourke 2014, O'Rourke et al. 2019). This principle is especially directed to leaders.

Principle 19: Draw lessons learned. Capitalize on what already exists by supporting systematic learning from existing data and knowledge (Mascarenhas et al. 2021). Draw lessons learned from and across particular cases and contexts (Krohn 2008, Adler et al. 2017). Encourage group members to learn from synthesis results and to assess their generality, transferability, and applicability to other cases and contexts (Hackett et al. 2008, Hampton and Parker 2011, Lynch et al. 2015).

Principle 20: Recruit integrative leaders. Appoint experts with experience and expertise in collaborative synthesis (Carpenter et al. 2009, Bammer et al. 2020, Hoffmann et al. 2022)—that is, experts who understand the processes as well as the methods and procedures through which heterogeneous perspectives can be linked and related to each other (Hoffmann et al. 2017b, Harvey et al. 2018) and who can transmit such experience and expertise to group members, therefore facilitating learning among group members and enhancing their capacity to leverage synthesis (Hampton and Parker 2011). Potentially, share or distribute leadership across group

Box 1. Background to the Swiss ProME.

In Switzerland, the Water Protection Act was amended in 2011 with the mandate to restore 4000 river kilometers and lake shores by 2090 (i.e., 6% of the entire hydrological network). Planned investments amount to 6 bn CHF (around 5.6 billion euros), with federal funding accounting for 35%–80% of the project costs and the rest being covered by the 26 cantons, municipalities or others (e.g., nongovernmental organizations). The Water Protection Act is being implemented in a two-step procedure: Every 12 years, the cantonal authorities perform strategic planning to prioritize river reaches for restoration. On the basis of the strategic planning, the local restoration projects are realized.

The Swiss Federal Office for the Environment (FOEN) launched a Program for Monitoring and Evaluation (ProME) for river restoration in order to allow for collaborative learning across stakeholder groups, an improved understanding of contextual factors bearing on project effectiveness and a means of transparently justifying resources employed (Weber et al. 2017). The ProME includes standardized field surveys (e.g., habitat diversity, fish, birds)—that is, river restoration projects in Switzerland do their monitoring and evaluation according to the ProME concept (FOEN 2019). Data are stored centrally and are used for cross-project analysis and elaboration of synthesis products, such as factsheets for restoration practitioners or scientific articles.

Data collected and analyzed within ProME are sensitive and political given that they have been financed by taxpayers and that outcomes are often characterized by a pronounced level of uncertainty and complexity. Therefore, ProME is designed as an adaptive management process (Allan and Stankey 2007), with the first 5 years designated as a pilot phase after which the ProME will be reevaluated and then run in 12-year cycles.

members (Krainer and Lerchster 2015, Hoffmann et al. 2017a).

Principle 21: Teach collaborative synthesis. Provide opportunities to teach and practice synthesis in ongoing inter- and transdisciplinary research projects or programs with a view to acquiring requisite experience and further developing distinctive expertise in leading, administering, managing, monitoring, or assessing collaborative synthesis (cf., Hoffmann et al. 2022) transferable to other synthesis endeavors (Hampton and Parker 2011). This principle is especially directed to leaders.

As was indicated above, the main purpose of the principles outlined in the present article is to guide leaders and team members attempting to lead and engage in collaborative synthesis rather than to prescribe how to apply these principles in a given context. They are also meant to encourage leaders and team members in recognizing their shared responsibility in providing both supportive and creative contributions to achieve such synthesis (cf. Mainemelis et al. 2018). We assume that the principles are mutually reinforcing (i.e., establishing a positive environment; e.g., enhances transformative learning, which, in turn, facilitates connections between different perspectives and, ultimately, enables creative synthesis). We further assume that working toward applying any of these principles in practice will add value to a given project or program, whereas applying them as a whole will probably imply a shift in the way creative synthesis is currently approached (cf. Fazey et al. 2018).

Empirical insights gained through the application of principles

In this section, we provide some empirical insights gained through the ex post application of our set of principles to

a major transdisciplinary research initiative, the ProME development project. The project involved the concept development for the nationwide ProME of river restoration projects in Switzerland and involved multiple levels of leadership and a wide diversity of stakeholder groups (box 1; Weber et al. 2017). The retrospective reflection on the benefits and challenges we encountered in developing such a nationwide monitoring program forms the empirical foundation of our tentative lessons for designing and implementing future inter- and transdisciplinary research projects or programs aiming at attaining creative synthesis.

The ProME development project lasted from October 2015 to February 2018 and was led by researchers (*integrative leaders*) from the Swiss Federal Institute for Aquatic Sciences and Technology (Eawag), including one of the lead authors of the present article. Project funding was provided by the Federal Office for the Environment (FOEN). ProME aims to produce standardized field surveys using biological, environmental, and societal indicators at local restoration projects in order to enable a collaborative learning process at the national level (i.e., across individual restoration projects), to improve the causal understanding of the factors influencing restoration effectiveness, and to justify the financial resources invested in river restoration, thereby increasing the credibility of restoration through a robust analysis of the effects (see box 1 for further information). The final product of the ProME development project was a synthesis report composed by the integrative leaders. In the synthesis report, different variants for a ProME were presented and compared. The synthesis report provided the basis for decision-making by FOEN, which took place in mid-2018. The chosen variant was described in detail in a guideline for practical application (FOEN 2019). Since 2020, the ProME has been operational—that is, in Switzerland-wide use.

The ProME development project represents an interesting and suitable real-world case for our empirical *ex post* reflection because of the following characteristics:

Leading across multiple levels. Given the federal structure of Switzerland, the planning and implementation of restoration projects vary regionally. Generally, the cantonal authorities lead the projects and mandate private consultancies for project planning, implementation, monitoring, and evaluation. At the national level, the FOEN takes the strategic lead—for instance, in distributing project funding, defining funding rules or in supervising projects of national concern (e.g., at transboundary rivers). Research institutes support the learning and implementation process—for instance, by leading the ProME development project.

Synthesizing across disciplines, fields, and sectors. River restoration is a truly inter- and transdisciplinary endeavor in which specialists and nonspecialists from different thematic fields and professional sectors and with various disciplinary backgrounds interact. Inherent in such activity is a diversity of interests, expectations, approaches, vocabularies, knowledge, and experience, making the synthesis process within ProME development a complex and demanding task.

Learning across diverse boundaries. Within each stakeholder group (i.e., federal and cantonal authorities, private consultancies), there is rather wide disciplinary diversity as there are always representatives involved from at least two major disciplines—ecology and hydraulic engineering. The diversity in vocabulary, methodology and culture is further amplified by continuous technological and methodological developments within each discipline (e.g., automatic data acquisition by remote sensing versus manual surveys) and by Switzerland's multilingualism with three of the four official languages actively used in practical river management (German, French, Italian).

Within the 2.5 years of the ProME development project, intense interactions involving leading, learning, and synthesizing were performed. In tables 1a–1f we present practical examples of such interactions according to the set of principles introduced earlier in order to visualize the principles' application in the particular context of the ProME development project. The examples range from organizational aspects (e.g., the formation of advisory groups; principle 2) to social aspects (e.g., proactive behavior; principle 15), to planning (e.g., timing of synthesis report; principle 5), right up to the provision of technical solutions (e.g., external support for database built up; principle 18). Most examples relate to work within the three advisory groups with representatives from different scientific disciplines, thematic fields, and professional sectors (see table 1a–1f for more detail).

In tables 1a–1f, we also compile the benefits and challenges we encountered within the ProME development project, again sorted by principle. Our list reveals the considerable difficulties that can emerge when diverse groups of stakeholders work together. The challenges arise from uncertainty inherent in adaptively managing a project on a national scale (e.g., principle 12), from the enormous diversity in worldviews, beliefs and assumptions between and within stakeholder groups (e.g., principle 4), from leading a transdisciplinary endeavor without major previous experience (e.g., principle 1) and from collecting and managing the many lessons learned in an ongoing process (e.g., principle 10). At the same time, our compilation in tables 1a–1f also indicates the many benefits such transdisciplinary collaborations bear, be it for the integrative leaders (e.g., principle 17), the members of the advisory groups (e.g., principle 19), the entire river restoration community (e.g., principle 16) or the wider public (e.g., principle 7).

The complex framework and context of the ProME development project made the role as an integrative leader both exciting and challenging. The task was exciting because it included a 2-year journey of intense transdisciplinary collaboration, which offered the opportunity to explore the perspectives of experts from other scientific disciplines or professional sectors, to establish trustful personal relationships, and to jointly celebrate achieved milestones in a shared agenda. Furthermore, given that there has not been any comparable initiative in Switzerland or elsewhere, the course of action was usually neither obvious nor prescribed, which left the integrative leaders with a lot of freedom to suggest creative solutions or explore new ways of thinking and working.

Assuming the role as an integrative leader was sometimes challenging because all decisions required iterative negotiations with the different stakeholder groups. Given the breadth of topics and the lack of specific knowledge or skills among all of them, these negotiations often took place outside the personal comfort zones of the integrative leaders, which demanded courage and self-confidence, even more so as a woman in a still male-dominated environment. Furthermore, leading ProME required a constantly high level of activity from the integrative leaders—for instance, in responding to rapidly changing agendas or emerging opposition from the various stakeholder groups or in being proactive by anticipating future developments or dynamics. In summary, leading ProME was a wonderful opportunity for personal learning, the acquisition of specific skills (e.g., communication) and improvement of systemic understanding (e.g., organizational differences across cantons). Personal characteristics certainly aided effectiveness in leading the ProME development project by facilitating capabilities such as a general adaptability to change, the persistence to keep on track of project activities, also in challenging times, or the ability to cope with ambiguity and uncertainty. However, a pivotal foundation for the project's success and final

Table 1a. Leading for synthesizing. Examples of principles applied within the ProME development project (2015–2018), with the benefits and challenges experienced when applying the principles (ex post reflection).

Principle	Example	Benefits	Challenges
Design synthesis process (1)	Structured cocreation of the synthesis report: The synthesis process was launched as an open, but product-oriented process over which integrative leaders and restoration practitioners collaboratively and interactively developed the structure and content of the synthesis report. At the onset of the process, the integrative leaders set up a rough time plan scheduling different phases of collaboration such as conceptualization, iterative reflection, consolidation and dissemination. Following an flexible approach, the time plan was continuously adapted over time.	Explicitly scheduling the synthesis process from the onset of the project and defining concrete phases allowed processes to be made concrete and transparent, where they are otherwise often perceived as vague, abstract or automatic.	Given that the ProME development was a worldwide unique endeavor, no previous experiences and recommendations existed for launching the synthesis process.
Form a diverse group (2)	Formation of inter- and transdisciplinary advisory groups: ProME development was supported by three advisory groups with representatives from different disciplines (i.e., ecology, river engineering), thematic fields and professional sectors: a national group with colleagues from federal and cantonal authorities and private consultancies, (b) an international advisory group with 5 scientists, (c) an internal advisory group from Eawag, the integrative leaders' home institution. The advisory groups critically reviewed and reflected on the suggestions elaborated by the integrative leaders.	Involving the major stakeholder groups into ProME development provided the foundation to develop a joint vision and gain acceptance for ProME as a new management and research initiative beyond the directly involved stakeholder groups.	Not all stakeholders could be included in the advisory groups as functional group size for effective workshops is limited (max. 15 persons).
Forge robust social bonds (3)	Discussion in subgroups: To ensure formal and informal interactions among members of the advisory group, the integrative leaders organized regular meetings with the three advisory groups over the 2.5 years of the ProME development project (e.g., 6 half- to full-day workshops for the national group and three 4-day workshops for the international group). Whenever possible, personal interactions between the group members were initiated during the meetings—for example, by prioritizing discussion in small interdisciplinary subgroups over frontal instructions and inputs by the integrative leaders.	Work in subgroups enabled a productive and intimate atmosphere and a direct exchange of perspectives among group members.	Social aspects, systemic views and critical reflections were perceived by some group members as irrelevant because they seemed not directly related to the topics discussed.
Connect diverse perspectives (4)	Inter- and transdisciplinary exchange: In-depth exchange across disciplinary and sectoral boundaries was actively fostered, with certain topics being discussed over several meetings—for example, by starting with a blue-sky thinking labelled explicitly as a warmup and no pressure at the first meeting, then a more focused brainstorming in groups at the second meeting, and then an evaluation of the written solution suggested by the integrative leaders at the third meeting. As such, the synthesis process became explorative from the beginning and synthesis steps could be explained in detail.	Making methodological, conceptual and cultural differences across stakeholder groups explicit led to serendipitous surprises, raised awareness of unexpected differences in underlying perspectives and assumptions, and facilitated transdisciplinary discussions.	Mutual understanding and critical connection of different perspectives was sometimes complicated because of disciplinary, cultural or language barriers or different individual frames of reference.
Create boundary objects (5)	Early start of synthesis report: The discussion about the format and outline of the final synthesis report for decision-making at FOEN was launched early in the ProME development—that is, at the very first meeting with each of the three advisory groups. In doing so, the synthesis report became a real, tangible item and an anchoring and target point or boundary object for all subsequent discussions. In an iterative, stepwise process, the synthesis report was developed further and requirements and inputs from different stakeholders could be included.	A design-thinking approach allowed for fruitful discussions, agile product development and efficient problem solving in the advisory group meetings, with the integrative leaders preparing specific propositions (prototypes) for the discussed topics and the group members suggesting concrete steps for improvement.	Introduction of multiple highly complex topics by the integrative leaders in one of the meetings with the national advisory group led to a “disorienting dilemma,” with group members being overwhelmed and confused about the overarching objectives of the project.
Assess new knowledge (6)	Discussion of preliminary results from synthesis: Preliminary results obtained through the process of synthesizing information from various sources (e.g., peer-reviewed and grey literature, stakeholder exchanges, data analyses) were discussed, reflected on and validated within the three advisory groups. Given the diverse background of the advisory groups (e.g., national versus international, ecology versus engineering), iterative discussions allowed complexity, national particularities (e.g., Swiss federalism) and disciplinary habits (e.g., representation of data) to be embraced.	The existing knowledge frameworks and worldviews of all project members could be continuously expanded by integrating new and often jointly developed findings.	Resources (e.g., time, expertise) were limited to receive comprehensive external feedback for all newly generated knowledge.
Disseminate new knowledge (7)	Consideration of windows of opportunity: Together with the advisory groups, windows of opportunity were identified so that future management recommendations from ProME can be most easily implemented by restoration practitioners. In the policy cycle, such windows of opportunity represent time periods in which important management decisions are being negotiated. Examples of windows of opportunity are the elaboration of strategic restoration planning by the cantonal authorities (every 12 years) or the negotiations pertaining to funding resources between FOEN and the cantonal authorities (every 4 years).	Regular updating of stakeholders, also from outside the advisory groups, on ProME development through targeted products (e.g., presentations, articles) guaranteed a consistent level of knowledge across stakeholder groups and supported a paradigm shift from project-based monitoring and evaluation toward standardization on a national scale.	Direct access to all stakeholder groups and their individual members as well as to the wider public proved to be limited because of time constraints to supply targeted information via the group-specific communication channels (e.g., stakeholder specific outlets or trade journals).

Table 1b. Synthesizing for leading. Examples of principles applied within the ProME development project (2015–2018), with the benefits and challenges experienced when applying the principles (ex post reflection).

Principle	Example	Benefits	Challenges
Provide common direction (8)	Contextual embedding (“big picture”): The three overarching objectives of ProME—collaborative learning, causal understanding, justification of resources—were highlighted repeatedly, be it at advisory group meetings or at national meetings of restoration practitioners. For each presentation, the overarching objectives were phrased in a consistent way, but tailored to the respective audience in order to highlight stakeholder-specific benefits from ProME, such as data sharing across projects or recommendations for site selection in strategic restoration planning by cantonal authorities.	Collaborative formulation of tangible objectives and milestones at the onset of the project provided guidance and orientation for project members and integrative leaders subsequently confronted with confusing discussions or particularly complex phases of the project (e.g., specifying minimal amount of monitoring and evaluation needed per project).	Getting support from advisory group members for joint overarching objectives and maintaining their commitment to such objectives over time was time-consuming.
Establish clear expectations (9)	Clear goals and agenda for meetings: For each meeting of the three advisory groups, clear goals and a detailed agenda were formulated by the integrative leaders and shared with the group members beforehand in order to clarify the planned content, form, duration and type of interactions at the meeting and to guarantee sufficient time for individual preparation. Goals and agenda were reintroduced at the start of each meeting and embedded in the big picture—that is, the overarching objectives of ProME.	Establishing concrete expectations about the timeline of ProME development and the role of the individual project members prevented frustration resulting from divergence between individual expectations and overarching objectives.	Adaptive management required regular adjustment of goals and expectations.

implementation of ProME on the national scale was the opportunity to collaborate within a trustful team of colleagues (i.e., integrative leaders and members of the three advisory groups) that shared a great enthusiasm for the joint objectives.

Discussion and conclusion

In the present article, we focused on the key interactions between three essential components of creative synthesis efforts—leading, synthesizing, learning—and compiled a set of 21 principles that guide these key interactions in inter- and transdisciplinary contexts. We applied our set of principles to a real-world case study—the development of a nationwide standardized monitoring and evaluation program for river restoration projects, the Swiss ProME development project—to reflect ex post on benefits and challenges in their practical application. In our reflection, we did not consider contextual factors that ultimately shaped the conditions under which this project took place. Acknowledging this limitation, we are nevertheless confident that our set of principles can offer valuable guidance for leaders and teams at the onset of a similar inter- and transdisciplinary endeavor—independent of the scientific disciplines, thematic fields, or professional sectors involved or the geographic regions concerned. Our principles as well as the reflections from the case study can introduce new integrative leaders to the complexity of the task and remind experienced colleagues of aspects they should keep in view.

Being inter- and transdisciplinary, long term, and large scale, the Swiss ProME development project provided a multifaceted real-world case to reflect on the benefits and challenges in applying our set of principles and to further polish them in light of our own experiences and the experiences of others in leading such inter- and transdisciplinary endeavors. Furthermore, our systematic ex post reflection

by means of the list of principles allowed for many useful insights that will support us in the operation phases of the Swiss ProME (i.e., from 2020 onward), as well as in leading future inter- and transdisciplinary research projects. We outline below three major lessons learned from such reflection on the principles applied in the ProME development project.

Lesson 1: Exemplified learning. A key element of the ProME development project was to design, implement and communicate *learning* as an intentional, clearly structured, and collaborative process (Weber et al. 2017, National Academies of Sciences, Engineering, and Medicine 2018) from the very onset of the project onward (principle 10). Doing so allowed the integrative leaders to clearly, transparently, and iteratively explain the benefits (e.g., understanding cause-effect relationships, sharing data) and the associated costs (e.g., financial resources) of learning collaboratively (principle 8). Furthermore, the scientific leaders were able to actively exploit the learning potential emerging from the confusion (or disorienting dilemma) within the stakeholder groups experiencing shifting frames of reference (Mezirow 1997). However, only in the ex post analysis based on the 21 principles did we realize that in all the discussions with the advisory groups and other partners about the mechanics of the learning process, the term *learning* per se was never explicitly discussed, exemplified, and consolidated (principle 5). Accordingly, the notion of transformative learning was misinterpreted by some stakeholders as implying a fundamental discontent among the integrative leaders and the FOEN with the current practice of river restoration. Furthermore, other stakeholders associated learning with school and education, which was not perceived as adequate for adults in a professional environment. To prevent misunderstandings, the integrative leaders adapted their terminology over the course of the ProME development project by translating

Table 1c. Leading for learning. Examples of principles applied within the ProME development project (2015–2018), with the benefits and challenges experienced when applying the principles (ex post reflection).

Principle	Example	Benefits	Challenges
Design learning process (10)	Collaborative learning process: Collaborative learning between stakeholders is one of the three overarching objectives of the ProME. Within the ProME development project, a major task with the advisory groups was to identify the key elements of a learning process (i.e., who wants to learn what until when and where) as well as the factors enabling (e.g., platforms for interaction) or hampering it (e.g., unclear duties). The learning process will be specified further in the first years after initiation of the ProME, including planned analyses and products, rough deadlines and responsibilities.	Collaboratively designing the learning process provided a predictable and plannable timeline agreed on by all project members.	Finding a suitable format and an appropriate level of detail for documenting the steps, roles and responsibilities in the collaboratively designed learning process and collecting, processing and sharing the lessons learned proved to be difficult because of the complex nature of a multiyear learning process involving many different stakeholder groups.
Establish a positive environment (11)	Diversified meetings: The meetings of the advisory groups were designed to be well structured, serious and formal, but at the same time playful, open and mutually beneficial—that is, structured in such a way as to take the different requirements and work contexts of the group members into account. A major focus in developing the meeting agenda was to allocate enough room and time for in-depth interaction among group members, productive work on specific tasks in subgroups and inter- and transdisciplinary exchange of experiences, questions and creative ideas.	A high productivity in the meetings and a sense of cohesion among group members was reached because of a transparent, friendly and constructive atmosphere.	One sole person could impair a positive environment—for instance, by repeatedly questioning earlier joint decisions or exhibiting lack of attention.
Facilitate transformative learning (12)	Shifting a paradigm: ProME represents a paradigm shift as monitoring and evaluation of river restoration in Switzerland is no longer planned and performed at the level of the individual project, but rather follows a standardized protocol at the national level. In all their communication (e.g., presentations, articles, newsfeeds), the integrative leaders invested particular time and effort to explicitly note the present and future paradigms, exemplify how the shift between the two can be operationalized, and transparently explain the estimated benefits and costs involved.	Thinking beyond existing boundary conditions was challenging, but provided the freedom and ease for thinking out of the box and enabled unconventional ideas, approaches and solutions to emerge.	The need for a paradigm shift toward standardization on a national scale was misinterpreted by some stakeholders as implying fundamental discontent with the current practice of river restoration and required a lot more time to explain and justify than initially expected.
Manage time and effort (13)	Iterate discussion of key points: Discussion of all key aspects for ProME (e.g., selection of standardized indicators, number and timing of field surveys) was launched early in the development process to allow stakeholders to respond and contribute with sufficient time, to anticipate future developments and trajectories and to prepare for unforeseen developments. From the beginning onward, discussion of key aspects was planned to be iterative in order to reach consensus, obtain mutual understanding and further collaborative learning.	Quality and quantity of returns (e.g., in discussions or by written feedback) increased when giving project members sufficient time for preparation, reflection and coordination (e.g., with internal colleagues from their respective institutions).	Unpredictable surprises or false assumptions (e.g., on financial organization in the authorities) disturbed original project plans.
Manage power relations (14)	Clarification of roles and needs: Roles and needs of the integrative leaders and the stakeholder groups and their representatives were made explicit in any collaborative activity (e.g., advisory group meetings) in order to foster respect, awareness and mutual understanding among stakeholders. For instance, in workshops that were jointly led by the integrative leaders and colleagues from federal authorities, it was defined beforehand who would answer which types of questions (e.g., regulatory questions versus methodological questions) to ensure that each stakeholder complies with their assigned role.	Explicit clarification of roles and needs guaranteed a constructive, fair and balanced atmosphere for discussions.	Regulatory interdependencies across administrative hierarchies cemented power relationships, making them very hard to be managed or changed.
Manage conflicts (15)	Proactive behavior: In exchange with the advisory groups, potentially conflicting issues between different stakeholder groups were anticipated and reflected in open discussions. For instance, multiple variants for a certain decision (e.g., number of restoration projects to be included in ProME) were compared and their potential opportunities (e.g., spatiotemporal coverage) and challenges (e.g., costs of field surveys, lack of personnel resources) identified and assessed regarding their relevance for the acceptance and implementation of ProME.	Approaching controversial and potentially divergent issues explicitly and proactively helped to raise mutual awareness of sensitive topics, ambiguous terms and complex framings.	The integrative leaders had multiple roles to fulfill in advisory group meetings (e.g., moderator, presenter, contributor, expert), which required explicit preparation before and critical awareness of potentially conflicting roles during the meetings.

the term *collaborative learning* into *exploiting collective intelligence*, which helped to get skeptical stakeholders on board. However, it would have been important to explicitly and formally agree on *learning* and other key terms from the

beginning in order to connect diverse perspectives (principle 4). Moreover, it would have been valuable to promote individual experiential learning and to reflect on challenges experienced by different members of the advisory groups

Table 1d. Learning about leading. Examples of principles applied within the ProME development project (2015–2018), with the benefits and challenges experienced when applying the principles (ex post reflection).

Principle	Example	Benefits	Challenges
Promote experiential learning (16)	List of open questions to guide action: Within the ProME development project, a list of open questions in river restoration research and practice was compiled in order to illustrate gaps in our knowledge, to raise awareness of uncertainties, and to provide a steering instrument to direct future activities (within ProME, but also within stakeholder groups) toward those topics requiring further information. Open questions were collected, reflected and shared within all three advisory groups and at two workshops with national and international researchers and restoration practitioners in order to cover a wide spectrum of disciplines, thematic fields and professional sectors.	Pursuing an adaptive management process (box 1) in ProME allowed continuous integration of lessons learned from many different stakeholders thereby improving the systemic and mechanistic understanding of research content and context.	Adaptive management included a reflection phase, which was a task on its own and which was often underestimated by the project members.
Support individual careers (17)	Plan and document the individual learning process: The integrative leaders collected the achievements and lessons learned for their personal development such as acquired skills, performed tasks, organized events, and overcome challenges. This list provided a useful basis for future positions and applications, within and outside of academia. In addition, regular reflection on their activities allowed the integrative leaders to actively plan and steer their individual learning, preventing pure provision of service from dominating their activities.	For young colleagues, supervised participation within a multifaceted project such as the ProME development allowed for developing the personal career on the fly—that is, in a real-world, concrete case.	Not every career path aspired to could be supported in the ProME development project; as a practice-oriented research project with limited output of peer-reviewed articles, it was unsuitable for persons aiming at a classical academic career.

Table 1e. Synthesizing for learning. Examples of principles applied within the ProME development project (2015–2018), with the benefits and challenges experienced when applying the principles (ex post reflection).

Principle	Example	Benefits	Challenges
Provide support (18)	External technical support: Quality-controlled raw data from ProME must be archived in a central database in order to allow subsequent cross-project analyses and long-term storage. Database build up exceeded the time resources and technical expertise of the integrative leaders within the ProME development project. Additional funding was therefore acquired by the integrative leaders to mandate an external expert for database design. Beforehand, the integrative leaders guaranteed that field forms met the general requirements of database design.	Dealing with technical characteristics of the data base for central data storage increased awareness of data quality issues, which range from data acquisition in the field to data entry or postprocessing.	Supporting external technical experts in their mandate (i.e., database design) proved to be very time consuming and demanding.
Draw lessons learned (19)	Formulation of lessons learned: As part of the collaborative learning process, major lessons learned from within ProME will be identified in regular intervals (e.g., every 2–4 years from 2020 onwards) and will be translated into recommendations for practical management (e.g., by listing factors to be considered in the strategic restoration planning that is performed by the cantonal authorities in 12-year cycles), and suggestions for reevaluating and optimizing ProME as part of an adaptive management process (in cycles of 4 and 12 years, respectively; see box 1).	Explicit reflection on lessons learned raised awareness of the joint achievements and motivated all group members to invest further in collaboration.	Stakeholders with little time and working in geographically separated places were difficult to integrate into collaborative efforts in general and in the synthesis process in particular.

Table 1f. Learning about synthesizing. Examples of principles applied within the ProME development project (2015–2018), with the benefits and challenges experienced when applying the principles (ex post reflection).

Principle	Example	Benefits	Challenges
Recruit integrative leaders (20)	Previous experience: The two integrative leaders of the ProME development project had a sound scientific background and good knowledge of the literature in relevant disciplines (biology, geomorphology), complemented by work experience in restoration practice (consultancy, cantonal authority). They were familiar with inter- and transdisciplinary collaboration and had good language skills (German, French, English) to exchange with the different local and international stakeholders. The integrative leaders were used to create diverse types of products (e.g., scientific articles, reports).	Affiliating the lead of the ProME development project with members of an applied research institute allowed for a fully transdisciplinary approach with a strong foundation in science (e.g., literature, expert networks).	Acquiring the funding for hiring experienced integrative leaders and finding suitable persons willing to run an applied research project that also provides products other than peer-reviewed articles (e.g., trade journal articles, reports) proved to be difficult.
Teach collaborative synthesis (21)	Platforms for informal exchange: Standardization of the field methods for ProME requires further education and platforms for exchange accessible to all stakeholders, independent of their background or experience. Those developing training opportunities have to consider that projects are highly decentralized, with project teams distributed across the country. One format that is used are informal online meetings open for all colleagues working on ProME in order to facilitate interaction across and within stakeholder groups. Participation is free and the focus is on peer-to-peer learning.	Peer-to-peer exchange or teaching proved to be a very valuable format for efficiently transferring critical insights (e.g., new findings that contradict common assumptions).	Explicit formats for teaching/training needed to be specifically created and reproduced in several languages (e.g., French, German, Italian) and involved finding skilled instructors and translators of courseware.

(principle 16) to acquire a better sense of the diversity of perspectives and perceptions regarding learning within the groups (principle 2).

Lesson 2: Distributed leadership. We found that leading is a complex and sometimes underestimated task requiring a clear and explicit definition of roles and an adequate distribution of responsibilities among diverse leaders (principle 20). In the ProME development project, leading synthesis was part of the mandate of the integrative leaders who were based at a research institute. However, aiming for a national concept to be implemented in a standardized way across several hundred restoration projects throughout the country required contributions, acceptance, and support beyond merely research personnel—that is, by all stakeholders. Accordingly, leadership had to be shared, distributed, and performed explicitly in order to be more effective (Krainer and Lerchster 2015, Hoffmann et al. 2017a). The federal authorities had—as a main funding agency for future ProME surveys—an initial key responsibility in learning to both lead the initiative from a strategic point of view and to explain and defend the paradigm shift vis-à-vis the cantonal authorities. The cantonal authorities then had a second key responsibility in learning to lead the implementation of the ProME by mandating private consultancies for the survey. During the ex post analysis based on our 21 principles, it became apparent that the different types of leaders would have benefited from explicit training and mentoring in collaborative synthesis (principle 21) to prepare them for their role and responsibilities and to make them aware of the challenges and opportunities that might arise over time. Furthermore, it would have been helpful to share and discuss the list of 21 principles among the different types of leaders at the very onset of the ProME development project to make the learning and synthesis processes more understandable and predictable (principle 11) and to manage expectations vis-à-vis the process (principle 9).

Lesson 3: Iterative synthesis. Organizing the synthesis process in the ProME development project was a highly iterative and adaptive journey. Intense collaboration with the stakeholders allowed for a well-structured process toward a clearly framed product tailored to the specific knowledge needs of intended audiences (principle 5; Hoffmann et al. 2017a) within the set time. However, the official implementation of ProME in January 2020 represents a veritable paradigm shift—from independent monitoring and evaluation of river restoration at the project level to collaboration and standardisation on the national scale (Weber et al. 2017). Accordingly, in the operation phase of ProME (2020) synthesis products will continue to be required—for instance, for periodically summarizing the lessons learned from cross-project comparison on the national scale (principle 19) in order to make them available for transformational learning at strategically important times (i.e., implementation in

strategic planning). However, in the ex post analysis based on our 21 principles, we realised that apart from clearly scheduled synthesis processes, also more continuous, iterative synthesis approaches as open-ended learning processes without predetermined outcomes or products will become important. Such iterative synthesis approaches are needed to maintain commitment among all stakeholders to joint objectives (principle 8) and to recognize, engage in, and build on one another's perspectives to generate and evaluate new knowledge (principle 6). To guarantee continuity and to manage stakeholder expectations (principle 9), technical and methodological support must be provided (principle 18) to expand traditional and well accepted activities such as colloquiums or online platforms for informal peer-to-peer exchange. Furthermore, this continuous learning and synthesis process also requires a certain level of explicit planning to become purposeful (principles 1 and 10).

Our set of principles proved to be relevant and useful for an ex post reflection on the case study selected. However, extending the application of our principles to additional projects would offer valuable insights into the relevance and usefulness of such principles for other thematic fields. Such application could encompass the full set of principles or individually selected ones, depending on the specific context (e.g., number of involved stakeholder groups) and the particular needs of a given project (e.g., level of interaction aspired to across stakeholder groups), or could involve subprojects or specific phases of a project only (e.g., concept development). Monitoring the three components and their interactions over time would allow for identifying contextual factors that influence the three components—leading, learning, and synthesizing—and their respective interactions. Conducting semistructured interviews and surveys with leaders and teams of inter- and transdisciplinary research projects aiming at achieving creative synthesis would allow for further refining, testing, and validating of our principles.

These prospects for further research notwithstanding, we encourage leaders and teams to place explicit emphasis on the three components—leading, learning, and synthesizing—and their specific interactions and to work toward applying any (or all) of these principles in practice with a view to fully exploiting the potential for creative synthesis in inter- and transdisciplinary research.

Acknowledgments

We thank Chris Zurbrügg for his valuable support in successfully completing this project and Pascal Bernhard, Lisa Deutsch, Benjamin Hofmann, Martin Schmid, Lucie Sprecher, and Christian Stamm for their useful comments on an earlier version of the manuscript. We thank Eawag, the Swiss Federal Institute of Aquatic Science and Technology, for providing the Proto-Synthesis Visitor Funds (to CM). We are thankful to anonymous reviewers for the valuable insights of synthesis as a type of integration and that leading for learning is not the same as learning about leading.