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ORIGINAL ARTICLE

Joint problem framing as reflexive practice: honing a transdisciplinary skill

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Abstract

The paper introduces a heuristic framework for conducting joint problem framing (JPF) processes in transdisciplinary research (TD). JPF is an essential element in confronting real-world problems, especially in the realm of sustainability (Hirsch Hadorn et al. in Ecol Econ 60(1):119–128, 2006; Pohl and Hirsch Hadorn in Principles for designing transdisciplinary research, Oekomm, München, 2007; Rossini in Technikfolgenabschätzung Theor Prax 18(1):117–119, 2009). It is the process of clarifying and prioritizing aspects of a problem situation to ensure its relevance for a diverse collection of stakeholders involved (Kønig et al. in Futures 91:12–24, 2017; Schneider and Buser in Sustain Sci 13(1):129–142, 2017; Stindt et al. in J Bus Log 37(2):113–131, 2016). The goal of this paper is twofold. First, we identify the documented challenges in conducting a joint problem framing process and through personal experience with case studies. Second, we introduce a means to address these challenges in the form of a heuristic framework. This framework is a series of questions which first asks for a description and explanation of the JPF process, based on researcher observations. Then, the framework leads its user to probe for the assumptions behind these observations. Finally, the framework helps its user to derive insights and lessons for conducting future JPF processes based on these responses. This framework is geared primarily towards helping transdisciplinary researchers with varying levels of experience, but can also be used by practitioners.

Keywords Joint problem framing · Transdisciplinary methods · Real-world problems · Tacit knowledge · Reflexive practice · Methodological heuristics

Introduction

The paper introduces a reflexive, heuristic framework to help researchers build capacity for conducting joint problem framing (JPF) processes in transdisciplinary (TD) research. There are a plurality of definitions for transdisciplinarity (Klein 2010; Pohl and Hirsch Hadorn 2007). We define TD research to be a subset of interdisciplinary research whose purpose is to both understand and develop solutions to societal problems, while accounting for their complexity and diversity (td-net 2019). This process involves the participation of non-academics who influence or are affected by the problem at hand.

In an attempt to engage with this "complexity and diversity", scholars have identified problem framing as an important element of transdisciplinary research (Hirsch Hirsch Hadorn et al. 2006; Pohl and Hirsch Hadorn 2007; Rossini 2009). Problem framing has generally been described as a process of "finding", "defining", "structuring" or "formulating" a problem. But what does it actually take to perform any of these actions? One is hard-pressed to find many detailed descriptions in the literature. In this paper, we use the following definition: problem framing is the process of eliciting, searching and selecting relevant perspectives that restructure one's perception of a situation, to determine the appropriate goals and criteria for the creation of effective solutions. In short, problem framing sets the goal and orientation of the problem solving activity.[1] *Joint* problem

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[1] Though we recognize that complex problems are never likely to be completely "solved", we use the verb as shorthand for describing a process of engaging with a problem situation such that the there is

framing is problem framing which takes place in a group setting, when diverse points of views are integrated to create a shared view of a problem.

The consequences of inadequate problem framing are evident in the efforts expended on behalf of sustainable development. Despite major movements and policy action, the global environmental quality has continued to decline (UN Environment 2019). A review of environmental policies across the world by Howes et al. (2017) revealed that vague policy goals, unclear terms, lack of guidance for how objectives can be achieved, conflicting objectives, and failure of communication regarding objectives are among the major factors accounting for failed environmental action. A lack of appreciation for the interconnectedness of problems also leads to poor or inaccurate problem framing (Dörner 1996).

Bardwell (1991) and Clark and Stankey (2006) have further characterized inadequate problem framing as solving the wrong problem, stating a problem too generally, stating a problem that cannot solved, or prematurely focusing on the solution before the problem has been accurately identified. An example of solving the wrong problem might be the implementation of more stringent standards for wastewater treatment to improve water quality, while most households are not yet even connected to wastewater treatment facilities. An example of stating a problem too generally might be a mayor's goal to "improve the well-being of citizens" during his tenure, with no accompanying criteria of how to define "well-being". An example of a problem that cannot be solved might be to "stop economic growth to prevent carbon emissions". It is a problem that can only be solved if the global economic structure is changed—probably not within the scope of any one particular project. An example of focusing on the solution before the problem might be to build centralized wastewater treatment plants in developing countries to decrease incidents of gastrointestinal infections, despite the lack of technical training available that would allow the system to be managed in the long run. The solution has been chosen without considering what the underlying structural causes of the problem might be.

While the need for problem framing has been identified, guidance for carrying out an effective problem framing process is not readily available in the academic literature (Cornell et al. 2013; Binder et al. 2015). The specific steps of carrying out a problem framing process remain vague and unspecified (Pohl 2011). We offer two reasons to explain this. The first reason: challenges to problem framing have not yet been systematically gathered. Case descriptions (Musvoto et al. 2015; Schäfer and Kröger 2016) of specific problem framing instances and descriptions of an ideal problem framing process (Lang et al. 2012) are available, but not a review and synthesis of the various challenges that could arise. The second reason: problem framing is a process that relies on tacit knowledge. Hard and fast rules for how to conduct problem framing processes are difficult to come by because while this knowledge might be exchanged or discussed, it is rarely written down or systematically collected. Researchers must, therefore, find their own approach to this challenging task, according to their own set of circumstances and abilities.

The aim of this paper is twofold. First, we identify conceptual and practical challenges in conducting a JPF process. Second, we introduce a heuristic framework addressing these challenges that would provide reflexive guidance in carrying out JPF processes. The heuristic framework takes the form of a series of questions that help researchers to reflect upon the key insights and lessons for conducting both ongoing and future JPF processes. The framework is built upon the identification of challenges to JPF from the literature, as well as the authors' own experiences with JPF. This framework is intended to help those just starting off in TD research by providing a means to structure new experiences, but also more advanced TD researchers who are interested in assessing and systematizing past experiences of JPF.

Definition of the main concepts

In this section, we introduce the main concepts we will use throughout this paper. We first develop on our definition of JPF as a form of problem framing that takes place in a group setting. Therefore, it requires dealing with actors from various social backgrounds, with various interests and who might have different mental representations of the problem. We then argue that many of the skills needed to deal with such situations are building on tacit knowledge acquired through practice in context. As tacit knowledge cannot be easily transferred through formal teaching or textbooks, we propose to rely on a heuristics framework to gather and reflect on tacit knowledge.

Joint problem framing

Problem types and problem framing

To define the term joint problem framing, we should first define what we mean by the term "problem". A problem

Footnote 1 (continued)

an improvement of the status quo. This process may never reach an endpoint in which everything is perfectly resolved. It is more likely to be an iterative process where problems are defined and redefined by those involved (Ison and Ampt 1992). Peter Checkland refers to problem solving as "purposeful activity" in situations regarded as problematical and a learning cycle that can be used to structure and debate future change (1985, 2000). This would be akin to our use of the term as well.

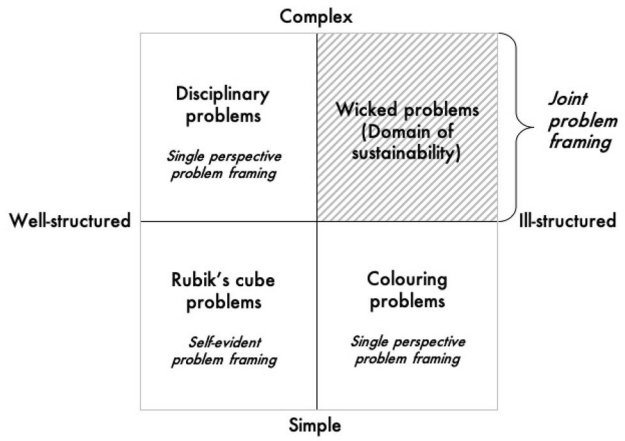

Fig. 1 Typology of problems. (Adapted from Jonassen and Hung 2008)

exists when a current state differs from a desired state (DeYoung et al. 2008; Newell and Simon 1972). Problems can be identified according to their complexity and to what Jonassen and Hung have referred to as "structuredness" (Jonassen and Hung 2008; Jonassen 2000). These dimensions determine the difficulty of the problem at hand. The higher degree of complexity of the problem, the greater breadth and depth of knowledge and experience needed to solve it. The less structured a problem is, the greater the number of unknowns, possible interpretations and possible solutions there are.

Using these dimensions of complexity and structuredness, four categories of problems can be formed (see Fig. 1). Located in the lower right quadrant, "Rubik's cube" problems are well structured and simple. Goals and the means by which to reach these goals are fully known. Though simple, considerable skill might still be required to apply the methods effectively. "Disciplinary" problems are also well structured, but complex. While the goal is clear and the approach by which the end goal will be reached is available, the ability to implement the approach appropriately depends on possessing a sufficient amount of knowledge and capacity to make links between disparate bodies of knowledge. Research problems which test a particular method or theory, for example, could belong to this type of problem. The term "disciplinary" is used to emphasize that these research problems are often found within disciplines, but are less common in interdisciplinary or transdisciplinary research contexts. "Colouring" problems are ill structured, but simple to solve. They require making a choice for which there is not a clear, "right" answer, but execution of any particular plan is straightforward. The decision to paint a house a particular colour, or, deciding what to draw on a blank piece of paper, would be examples of "Colouring" problems. "Wicked" problems are both highly complex and ill structured, and this is the domain of problems in sustainable development. They have multiple solution paths, have unclear goals, possess multiple and competing criteria for evaluating solutions, and often require the inclusion of personal judgements and values in the process of getting them more clearly defined (Rittel and Webber 1973; Dörner and Funke 2017; Alford and Head 2017).

How might problem types be related to the concept of problem framing? Problems of societal relevance are often complex and ill structured. They require the cooperation of many people to address and require a greater degree of problem framing because the outcomes affect a large group of people rather than select individuals. "Rubik's cube" problems may not require problem framing because the goal and the means to achieve it are already defined according to the context of problem solving. The frame is provided by the puzzle itself. Problem framing is self-evident. "Disciplinary" and "Colouring" problems, in contrast, do require problem framing, but only from one perspective. Problem framing of "Disciplinary" problems are driven by the needs of a specific expertise or through a community of people who share a similar education, social and/or professional background. For "Colouring" problems, what problem should be solved is not clear at the start because there are not set criteria by which to judge the appropriateness of a solution. As is the case for the activity of colouring, there is no universally agreed upon set standard by which to judge the "correctness" of the colour. The colour selection has to be carried out ultimately according to the colourer's own judgement of appropriateness (i.e., without additional criteria, a drawn cat can be coloured either grey or black). While the decision may not be a straightforward one, the activity of colouring itself is not difficult to accomplish. "Wicked" problems, in contrast to all other types of problems, require JPF. These problems are highly complex, ill structured and the problem outcomes can affect many people. As a result, these problems require the cooperation and buy-in from diverse groups for effective engagement. In these cases, JPF is required to clarify and prioritize aspects of the complex problem that is relevant for those involved, to ensure the relevance of the process and the outcome (Kønig et al. 2017, Schneider and Buser 2017, Stindt et al. 2016).

Existing definitions of joint problem framing

Now that we have established that joint problem framing is used in relation to complex, societal problems, we can go on to build a clear definition of JPF. "Problem framing" as a term was first used in the context of environmental problem solving by Bardwell (1991). Similar concepts have been referred to as problem restructuring (Davidson 2009), problem structuring (Checkland 2000; Dijk et. al 2017; Jackson 2017; Rosenhead 1996), problem definition (Hirsch Hadorn et al. 2006), problem finding (Getzels 1975) or problem

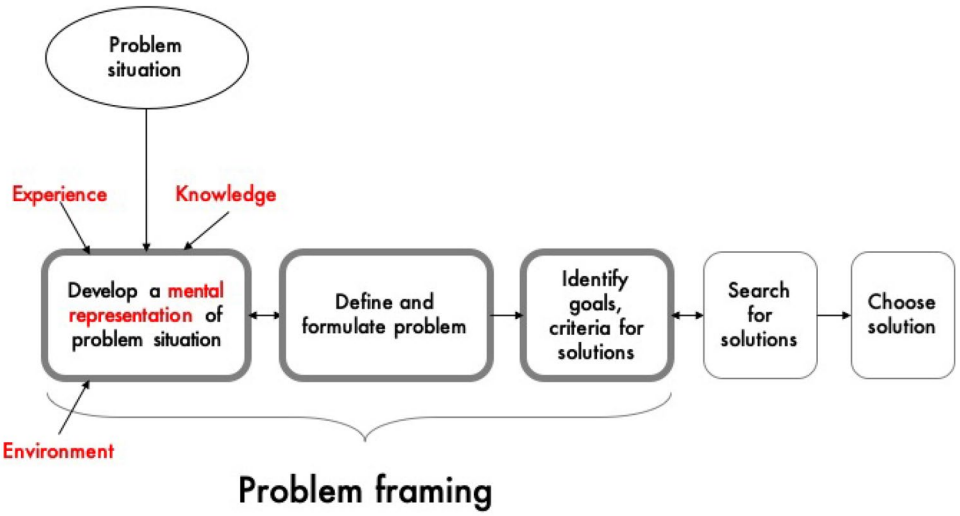

Fig. 2 Theory of problem framing. (Adapted from Newell and Simon 1972)

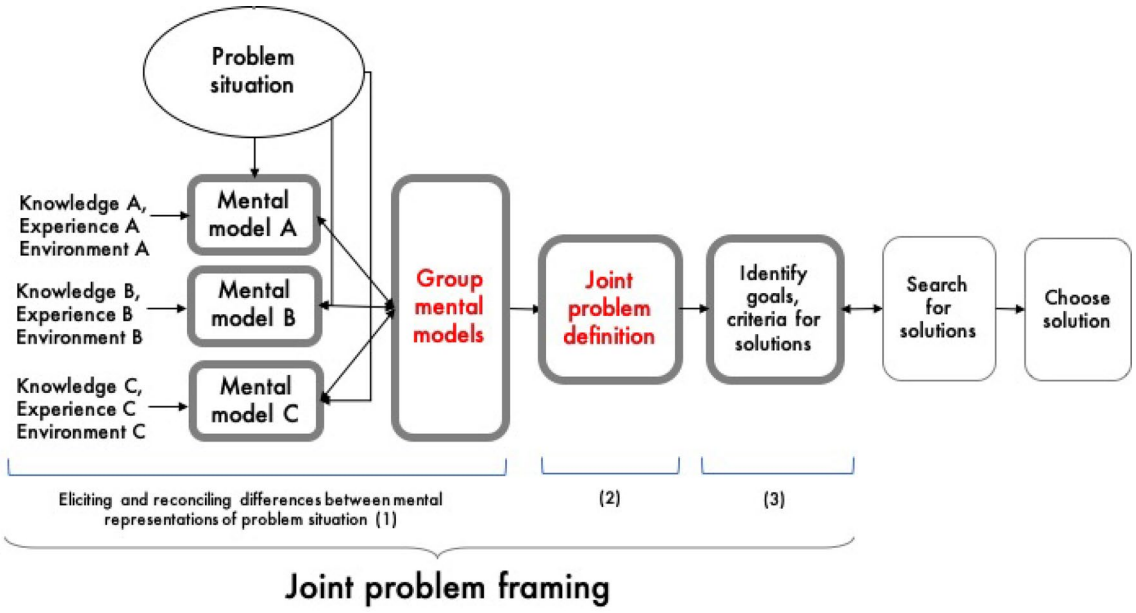

Fig. 3 Theory of joint problem framing. (Further adapted from Fig. 1)

formulation (DeYoung et al. 2008). In the context of transdisciplinarity, JPF has also been referred to as collaborative or collective problem framing (Lang et al. 2012; Schauppenlehner-Kloyber and Penker 2015; Stokols et al. 2010; Wiek et al. 2007) and problem transformation (Jahn et al. 2012). To our knowledge, a clear boundary has not yet been drawn between those actions which count as problem framing and those belonging to problem solving activities as a whole. Making this distinction is our goal in the following section.

Figure 2 provides a starting point for our understanding of problem framing, based on the theory of problem solving developed by Newell and Simon in (1972). Newell and Simon lay out five steps of problem solving. We claim that of these five steps, three belong to problem framing: (1) developing a mental representation of the problem situation, (2) defining and formulating the problem, and (3) identifying the goals of problem solving and the criteria for evaluating solutions. We do not include searching for or choosing solutions as a part of the problem framing process.

The development of a mental representation of a problem situation is a product of an individual's experiences, knowledge and environment (Newell and Simon 1972). Together, these factors contribute to what can be referred to as a "mental model" (Johnson-Laird 1983; Knauff 2013; Pearce 2015) or mental representation of a problem situation. In single-perspective problem framing, the mental representation comes from an individual or a homogenous group that is not challenged. In contrast, multiple mental representations

are present in a JPF process. The process of integrating these different mental models to create a group mental model is unique to the JPF process (See Fig. 3). The first step of JPF is to elicit and reconcile these differences between mental representations of a particular problem situation. The second step is to jointly define and then formulate the problem, where formulation is created and agreed to by those holding diverse mental models. The joint problem formulation is the starting point for the third step of JPF, which is identifying goals and criteria for solutions together.

These steps form an idealized template for JPF that we now use to compare varying descriptions of JPF in the literature. Within the scope of the literature review that was conducted, five papers provided sufficient details about the JPF process to enable a comparison (see Table 1). Our concept of JPF seems to match what others have found to a great degree, although different vocabulary is used to describe each of the steps. JPF is a group process, which means dynamics relevant to all group processes are also relevant to JPF. However, in this paper, we choose to focus only on the challenges of group interaction which are specific to the JPF. For a more detailed discussion of how group processes relate to TD research, see Schauppenlehner-Kloyber and Penker 2015.

Team formation (Lang et al. 2012; Jahn et al. 2012) is also an important aspect of JPF that we see belonging to the first step of JPF where differences in mental representation are being elicited and reconciled. Identifying who belongs to a team, confronting differing norms, interests and goals within the team are all processes which can be seen as making explicit and reconciling differences in mental representation.

Tacit knowledge

Developing competency for JPF relies on accessing tacit knowledge (Leonard and Sensiper 1998). Tacit knowledge is built up of embodied experience that gives rise to unformulated and implicit rules about what to do in a given situation (Leonard and Sensiper 1998). It is a subset of experiential knowledge with the additional character of being difficult to transfer to another person by means of writing or verbalization. Examples of tacit knowledge relevant for JPF are: knowing how to engage with diverse points of views, listening and integrating different types of knowledge, knowing whom to work with to move towards the project aims while flexibly dealing with shifting contexts. In the management literature, tacit knowledge is discussed as something that can be "harnessed" by making "tacit rules" explicit (Lam 2000; Mascitelli 2000). This perspective assumes that all tacit knowledge may be easily transferred from one person to another. However, we make the point here that there are different types of tacit knowledge and how they can be accessed depends on these distinctions.

Table 1 Definitions of joint problem framing

Steps in problem framing (from Fig. 3)	Jahn et al. (2012) "Problem transformation"	Lang et al. (2012) "Collaborative problem framing"	Schäfer and Kröger (2016) "Joint problem framing"	Stokols et al. (2010) "Collaborative problem framing"
1. Eliciting and reconciling differences in mental representation	The given societal problem is transformed into a boundary object. Team formation through a reflexive, methodically guided process that balances tensions between differing norms, interests and goals	Identification and description of the real-world problem Building a collaborative research team	Integrating complementary or fragmented aspects of system knowledge and provide an impression of the range of perspectives	Characterizing the problem What exactly the problem is and for whom?/Which assumptions and which type of knowledge help us to understand the problem?/What is the context in which the problem is meaningful?
2. Problem definition/formulation	Boundary objects are transformed to epistemic objects by applying theories or concepts	Joint formulation of objectives and specific research and socially relevant questions	Develop a mutual understanding between different perspectives and establish a common basis for further cooperation	Finding common goals and language amongst different framings of the problem
3. Identifying goals, criteria for solutions	–	Design of a conceptual methodological framework for knowledge integration	–	Search for possible solutions Identifying resources needed to solve the problem

Collins (2001) describes three metaphors that elicit these distinctions:

- *Skills-motor* tacit knowledge is embodied knowledge that is guided by motor skills which does not involve cognitive recognition of the rules that guide the task. Physical experience of the thing that is to be learned is essential and no amount of conceptualization would replace this experience. Riding a bike, for example, is a type of skills-motor tacit knowledge.
- *Rules-regress* tacit knowledge is knowing the implicit rules that should be followed in certain situations. The rules are implicit because there is a difficulty in describing exactly under which circumstances a certain convention would apply. Rules are passed down through tradition, culture or custom and could be partly formalized, though it will always rest on unarticulated knowledge.
- *Forms of life t*acit knowledge starts with acknowledgement that different people take on different information to be certain knowledge. These differences are acquired through socialization. What one individual might take to be obvious may not even occur to another due to these differences. Tacit knowledge remains tacit because of the distance between these perspectives. This type of tacit knowledge is difficult to transfer because it requires a willingness to delve into another point of view.

The "forms of life" tacit knowledge is most relevant for JPF because these are social situations in which researchers must be attuned to nuances of behaviour and attitudes. For instance, researchers should be aware if stakeholders are making ironic declarations, or whether some actors' attitudes signal animosity towards others or the whole process. This type of tacit knowledge cannot be easily verbalized or written to transfer from one person to another. However, it can be accessed retrospectively by individuals engaged in practices and social situations by means of reflexive knowledge, that is, knowledge that critically examines past actions to make sense of them (Bourdieu 1998; Giddens 1984; Schirato and Webb 2002). We propose a procedure that utilizes reflexivity to access "forms of life" tacit knowledge. By becoming aware of the actions that are being taken, why they are being taken and how they are being taken, one is able to build upon a priori experiences, knowledge and skills to create a new, more nuanced understanding of the current situation (Shirato and Webb 2002). This procedure makes use of Donald Schön's (1984) concept of "reflection-in-action."

A heuristics framework

We use a heuristics framework to build and develop skills and competences for JPF in this paper. Chow's (2015) definition of heuristics and his identification of methodological heuristics is our starting point for creating a heuristics framework: "Heuristics are satisficing cognitive procedures that can be expressed as rules one reasons in accordance with". Methodological heuristics are "devices for learning and problem solving". Similar to models or analogies, methodological heuristics help us to make sense of the world through re-representing it for ourselves and learning from these re-representations that make tacit aspects of our world explicit. This definition contrasts with the most well-known application of heuristics, established in the field of psychology with the "heuristics and biases" programme (i.e., Tversky and Kahneman 1986). Here, heuristics are defined as mechanisms used unconsciously by people to minimize cognitive load and to simplify decision making. They are shortcuts to an approximate answer. In contrast, methodological heuristics are used consciously as aids. Users of methodological heuristics are able to reflect upon, revise and change them as needed.

The "heuristics framework" developed in this paper is a form of methodological heuristics. It is a set of questions applied to a JPF process, asked in a specific procedure, whose answers help to elicit and develop observations, perceptions and insights that would otherwise remain implicit. The framework does not provide a definitive set of answers for how to "do it right", but rather relies on gathering personal experience and pattern matching to reveal how processes can be improved. Gary Klein (1998), in his extensive study of how expertise for complex, rapid decision making is developed, points out that the ability to match patterns and solutions accurately based on previous, similar contexts is the key difference between expert and novice practitioners. This heuristics framework helps researchers become aware of assumptions and the tacit knowledge used during the process, such that she or he is able to make conscious choices about how to shape and facilitate future JPF processes. Such an approach is also in line with Donald Schön's (1984) concepts of "reflection-in-action" and "reflection-on-action". Rather than using preconceived ideas based on a theory about what should be done, one is able to decide on what actions work best for each particular set of circumstances, both in the moment ("reflection-in-action") or for future incidences ("reflection-on-action").

Challenges for joint problem framing

The existing literature points out that there is a need for improved problem framing processes in transdisciplinary research, but the concrete practices and methods for carrying out this process remain underdeveloped. To find this out, we first searched existing papers containing the keywords "problem framing" and "transdisciplinarity" and "sustainability", with the goal of trying to find papers with concrete

information and guidance on how researchers can carry out an effective JPF process. The search was motivated by our own needs as researchers to substantiate personal experiences with JPF in the published literature. We did not find any papers that matched our specific needs. The cohort of papers did, however, provide a foundation from which we could assess existing challenges to JPF. We collected and clustered the challenges found in the literature, which gave us the starting point for how we might design a framework for JPF.

Using the terms mentioned above, only a small number of papers were returned in databases (3 in Web of Science, 16 in Scopus). We, therefore, expanded our search to Google Scholar where 456 papers were returned. Of these, we looked for peer-reviewed journal articles that provides one or more of the following: (1) a definition of "problem framing" or "joint problem framing", (2) an identification of a specific challenge of problem framing, and (3) a description of applying of problem framing to a specific project. This narrowed down the number of relevant papers to 154. We did not include the literature on problem-structuring methods in operational research to keep the focus on the concept of problem framing as it is used in the field of transdisciplinarity and on topics of sustainable development. Of these papers, 38 mentioned specific challenges to problem framing.

We clustered challenges related to the JPF process by categorizing the statements mentioning "problem framing" given by each relevant paper. We found two main types of challenges that were mentioned: content-oriented and process-oriented. The content-oriented challenges are related to the complexity of the problem itself. The process-oriented challenges are related to the implementation of the JPF process.

The content-oriented challenges of JPF reflect the core characteristics of complex or wicked problems, as defined by Dörner (1996) and Rittel and Weber (1973). These content-oriented challenges are:

- The existence of unforeseen linkages between system components
- The dynamic nature of the problem situation
- Inadequate access to knowledge
- The presence of a plurality of perspectives and interests
- The presence of large amounts of unstructured information related to the problem situation.

The process-oriented challenges centre around three types:

- Quality of interaction between different stakeholder groups involved in a project
- Knowledge of concrete methods which are known to be effective
- Availability of time and financial resources to foster collaboration.

Figure 1 shows that the content-oriented and process-oriented challenges are interlinked and overlap, as described in the literature. For example, in confronting the challenge of facing a plurality of perspectives in a problem situation, the researcher needs to be able to facilitate quality interactions that enables different stakeholders to find common ground. In the following section, we describe each of the challenges in more detail.

Content-oriented challenges

There are five core challenges related to the inherent complexity of the problems that are dealt with in a JPF process. Complex problems exist in the presence of:

- Plurality of interests and perspectives—the existence of a diverse set of perspectives is the norm for complex, wicked problems. During JPF, when each perspective has to be expressed and accounted for, it is difficult to manage the balance between an "efficient" process and a process in which these perspectives could be effectively incorporated into a final outcome. In the presence of different world views, there is a tendency for each person to lean towards his or her own habits of thinking. This has to be reconciled with other habits of thinking, to arrive at an agreement (Bardwell 1991; Brandt et al. 2013; Felt et al. 2016; Fischer et al. 2014; Guimarães et al. 2018; Krueger et al. 2016; Lang et al. 2012; Lee et al. 2018; Mielke et al. 2017; Spangenberg et al. 2015; Schodl et al. 2015; Steelman et al. 2015; Stokols et al. 2010; Tobias et al. 2018; Vilsmaier and Lang 2015; Walzer et al. 2013; Wuelser and Pohl 2016; Yates et al. 2015; Rogga et al. 2018).
- Access to knowledge—there is a lack of available knowledge regarding whether a certain solution is the "right one". Knowledge for deciding on what criteria should be used to judge the quality of solutions is often also lacking. This lack could be due to information not being available or a lack of resources to access already available information (Foley et al. 2016; Galway et al. 2016; Lee et al. 2018).
- Unstructured information—information has to be structured so that there is a bias towards action rather than "analysis paralysis" (Silver and Hecker 1970), while important details are not overlooked (Brandt et al. 2013; Kerkhoff 2014). There is a need to present the available information to participants such that there is a balance

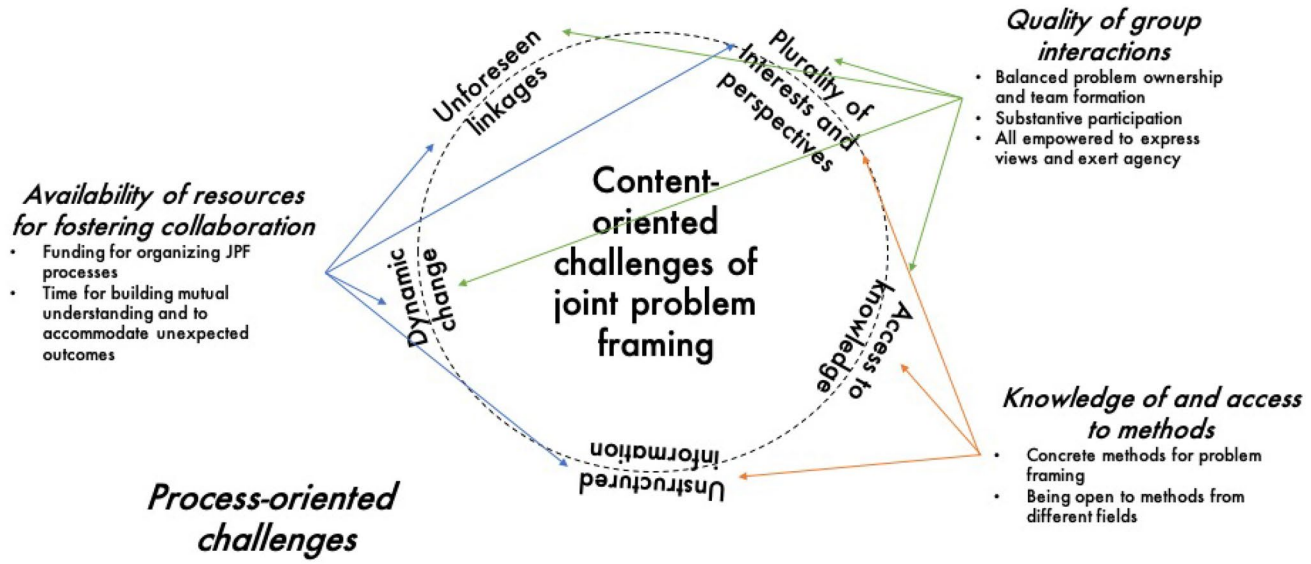

Fig. 4 Content- and process-oriented challenges to problem framing

between clarity and ease of communication with accuracy and comprehensiveness.

- Dynamic change—adapting to new information or changes in the situation are necessary. This might require patience, since a JPF process might be iterative, rather than linear (Roux et al. 2017; Steelman et al. 2015). This might mean that the same point has to be discussed several times before the project can go forwards, or that it may be necessary to go backwards to discuss a previous decision before being able to go forwards again. A readiness for change and the ability to be flexible is central to this way of working.
- Unforeseen linkages—there are many variables or factors interacting with one another in unexpected ways, leading to emergent insights and unintended consequences (Huber and Rigling 2014; Kerkhoff 2014; Midgley 2000). The JPF process has to remain adaptive to the possibility of the unforeseen. Systems thinking, scenario planning and including different types of expertise are approaches during the JPF which can help illuminate complex relationships.

Process-oriented challenges

In addition to the challenges inherent to the complexity of the problem, the second type of challenges we identified are focused on the practical challenges of carrying out JPFs. These challenges relate to the quality of group interaction within a project, knowledge or access to concrete methods which are known to be effective for JPF and the availability of time and financial resources to foster collaboration.

- Quality of group interactions—the quality of group interactions has implications relates to the ability to deal with unforeseen linkages, to address the plurality of perspectives during the JPF process and to enable access to knowledge (see Fig. 4). The higher the quality of group interactions, the better able the group members are to rely on each other to fill in knowledge blind-spots and perhaps to better anticipate otherwise unforeseen linkages. Quality of group interactions in the context of JPF has been linked to the ability to compose a TD research team that can collaborate effectively. The literature cites the tendency of scientific participants to take over the ownership of the problem (Lang et al. 2012; Schodl et al. 2015). Participation of different actors should be substantive, rather than symbolic (de Jong et al. 2016). The quality of group interaction is also whether participants are able to understand and accept each other's interests (Hirsch Hadorn et al. 2006). This implies that participants have to overcome possible misconceptions about each other (Payne et al. 2013). A process designed to empower all participants to express their views and to exert agency (Svihla and Reeve 2016) would be necessary for this to occur.
- Knowledge of and access to methods for JPF—there is a lack of access and use of concrete methods and methodologies specifically for conducting JPF processes. This challenge is related to content-oriented challenges of engaging with a plurality of perspectives and interests, being able to access knowledge and dealing with large amounts of unstructured information (see Fig. 4). When concrete methods for JPF are applied and evaluated, it becomes more possible to improve the process

and build on previously collected knowledge. While there are tools available for transdisciplinary research methods in general, (see the td-net methods toolbox https://naturalsciences.ch/topics/co-producing_knowledge/about), they are not specifically for JPF. There are also many "problem structuring methods" (PSMs) in the field of operations research (OR) (i.e., Rosenhead and Mingers 2001) and also those used in multicriteria decision analysis (i.e., Keeney 1996) that are not accessed regularly by transdisciplinary researchers. Efforts such as the Integration and Implementation Insights (I2S) platform (https://i2insights.org/) collects tools from a diverse range of fields are also available. However, there is still untapped potential in interdisciplinary exchange between these fields where well-developed methods from operations research can be explicitly adapted for transdisciplinary research. All this requires a willingness on the part of TD researchers to be open to different approaches.

- Availability of resources for fostering collaboration—this challenge is linked to a team's ability to deal with the complex nature of sustainability problems. Without sufficient funding or time, it is difficult to overcome the difficulties of unforeseen linkages, dynamic changes of the problem situation and processing large amounts of unstructured information. Funders assume that the problem has already been formulated in the grant proposal (Hirsch Hadorn et al. 2008; Hoffmann et al. 2017), which means that JPF processes are often not funded. Researchers might have to initially frame the problem alone to apply for funds for a TD process (Hirsch Hadorn et al. 2008) or researchers have to reduce the time allocated for JPF processes to meet deadlines (Zscheischler et al. 2017). Time is also a key resource for conducting successful JPF processes (Fischer et al. 2014), and TD projects in general (Huber and Rigling 2014). Time is needed to develop mutual understanding and to develop trust amongst project partners. Since the process is dependent on people and an openness to change, unexpected outcomes are inevitable. Additional time is also needed to negotiate this inherent dynamism.

To summarize, the challenges of JPF are connected to the complexity inherent to the problem being worked on and to the resources available to the researcher working on the problem. We have identified five challenges related to aspects of complexity and three challenges related to process-oriented needs. In this way, we can understand the nature of challenges to JPF as an interaction between the nature of the problem and the needs of the researcher to adapt to this complexity. In a further step, we provide a framework which works on the interface between these two groups of challenges.

A heuristics framework for joint problem framing

The challenges described in the previous section serve as the foundation for the design of the heuristics framework we now present in this section. The purpose of the heuristics framework is to: (1) bring attention to challenges related to both the complexity of the problem itself and process-oriented, practical concerns of running a JPF process, (2) record observed actions to serve as a reference for future JPF processes, and (3) make explicit researchers' assumptions and explanations about why and how things occur in conducting a JPF process, which normally is retained only as tacit knowledge. The framework is intended to be used as a reflexive tool to learn from each instance of JPF, meaning that it can be used to evaluate a project either during its lifespan or ex-post. It is our hope that researchers are able to gradually develop an enhanced capacity for conducting effective processes by explicitly examining assumptions or habitual interactions in group settings. For those who are not yet experienced with JPF processes, it could also be used as a means of acquainting oneself with possible challenges before heading into a project.

The heuristics framework we propose is built around a set of guiding questions presented in table form and linked to known challenges of JPF (see Table 2). Running along the vertical axis are guiding questions linked to each challenge. There is one set of questions to represent each aspect of complexity and another set of questions to represent each research-oriented challenge. The questions related to the challenges inherent to complexity are:

- Plurality of interests and perspective—what were the different interests and perspectives present in the project?
- Access to knowledge—what were the knowledge bases on which actors relied upon during the project?
- Unstructured information—what were the sources of information and data that had to be communicated and negotiated between participants?
- Dynamic change—what were the expected and unexpected changes that happened during the JPF session(s) and/or during the course of the project overall?
- Unforeseen linkages—what were the unforeseen linkages of people and components of the system that appeared during the JPF sessions(s) and/or during the course of the project overall?

The questions related to the process-oriented challenges are:

Table 2 Matrix of the joint problem framing heuristics framework

The "What"—guiding questions linked to key challenges of JPF note down your initial impressions	The "How"—how do you know what you described in the previous column? Recall specific instances and observations	Insights—what was something surprising that you learned from reflecting on columns 1 and 2, if any?	Lessons learned—how might you be able to apply the insights to future processes?
Challenges related to complexity			
Plurality of perspectives and interests		What were/are the different interests and perspectives present in the JPF process?	
Access to knowledge		What is the basis of knowledge that actors relied upon during the JPF process?	
Unstructured information		What were the sources of information and data that had to be communicated and negotiated between participants?	
Dynamic change		What were the expected and unexpected changes that happened during the JPF session(s)?	
Unforeseen challenges		What were unforeseen linkages that appeared during the JPF process?	
Process-oriented challenges			
Quality of interactions		What actions were intentionally or unintentionally taken during the JPF process to enable interactions during the JPF process? What were the effects of taking these actions?	
Knowing and accessing methods		What concrete methods (if any) were used intentionally for the JPF process? What were the effects of these methods?	
Availability of resources for fostering collaboration		What resources (e.g., time, funding, etc.) were available for conducting the JPF process?	

- Quality of interactions—what actions were taken to enable good-quality interactions between participants in the JPF process? What were the effects of these actions?
- Knowing and accessing methods—what concrete methods (if any) were intentionally used during the JPF process? What were the effects of these methods?
- Availability of resources for fostering collaboration—what resources (i.e., time, funding, etc.) were available for conducting the JPF process?

By answering the guiding questions on the vertical axis, researchers construct structured stories that relate to the main challenges of JPF.

Along the horizontal axis, the framework draws out the experiences of researcher in increasing detail from left to right and eventually helps the researcher to extract insights from these experiences and then to formulate lessons for future processes. The sequence of questions starts with recalling observations and facts related to each challenge. Answers to the primary question in the first column elicits the "What" of the situation and should lead to a description of actual experience and process of the JPF linked to the particular challenge from the perspective of the researcher.

The secondary questions probe into the "How" of the given descriptions. Going beyond initial explanations, these questions help researchers reflect on the evidence and actual experiences that he or she used to answer the "What" question. For example, when reflecting on how the researcher came to attribute interests to participants to the workshop, he or she might reflect on whether the participants expressed their interests in public or bilaterally, whether some participants attributed interests to others or whether it was based on assumptions, etc. The table provides some prompts for what these questions can look like.

However, there is not a fixed form that must be followed for these secondary questions. They can be changed and more questions can be added, as is fitting to the specific context. Asking the user of the framework to describe the events of the JPF process and then asking how the researcher knows that these are indeed the circumstances of the process, makes the researcher become aware of the assumptions that were used to interpret the events. The goal of this reflection is to help the researcher uncover previously held assumptions about the participants and their interests or relationships to one another and to see which of these assumptions are founded, and which are not.

From the "What" and "How" of a problem- or process-oriented challenge, the next stage of questioning asks researchers to identify "insights" from answering the first two questions.

The working definition of "insight" in this paper is adapted from existing formulations (Davidson 2009; Kaplan and Simon 1990) to be a piece of information

which results in a restructuring of previously held assumptions, which results in an "AHA!" experience of the receiver of information. As opposed to a fact, or a single piece of data, an insight has explanatory power which necessitates interpretation prior to use. A habitual path of thinking is changed into a new direction and new meanings arise from old experiences. The insight is not bound to a specific length or format, but can be explained concisely. In the third column of the framework, then, researchers are asked to reflect on the "What" and the "How" of the related challenge to pinpoint "insights". In the process of this reflection, researchers learn more about how the JPF process can be affected by these assumptions and what might make for a more effective process. Going along the horizontal axis of the table provides a way to re-contextualize these stories through recalling specific situations in which they were produced. This operation reconnects insights gained during the process with (some of) the contextual conditions is what allows the researcher to tap into tacit knowledge.

The framework then leads researchers to go one step beyond these insights to ask, how might these insights be put to use in future projects or in the next step of the same project in the "Lessons learned" column. It may be possible that the researcher may not yet realize what the lessons learned are at the time in which the table is being filled in. This is not a hindrance. In these cases, we would encourage the researcher to come back to it later, after more experiences have been accrued or sufficient time has passed to allow for more reflection. We would encourage researchers to fill out the first two columns of the table with as much detail as possible, because without this foundation, it would be difficult to extract information for the last two columns in the future.

We illustrate how researchers can fill in the table, by reflecting on a past JPF process in which one of the authors was involved (Ejderyan 2014): the process was conducted in the context of a river restoration project in the Geneva region in Switzerland. Though not explicitly labelled as a transdisciplinary research project, its aim was to integrate the views of multiple stakeholders with different perspectives to solve a particular problem and to understand the process of these changes happen. The project was initiated by the cantonal government to improve the flood protection of a downstream urban area while enhancing ecological functions in a rural area. The Genevan farmers' union originally stated that it would not oppose the project if the loss of arable land was minimized and if flood protection was extended to farmlands. The canton tried to accommodate these requests by proposing to use farmland to widen the riverbed and create a flood retention basin. The farmers within the project area then opposed this project, however, arguing that it would dramatically change the local landscape and cause an irreversible loss of farmland for relatively minor ecological benefits.

As the research project started, a series of workshops were held to gather the farmers, engineers in charge of designing the project, environmental NGOs, local authorities and residents. These meetings were meant to clarify why the restoration plan had been rejected. During these meetings, it emerged that farmers whose land would have been affected did not think the flooding would be a problem, even if the size of the flooded area is relatively large, if the land is submerged for 3 days or less. This information enabled a reframing of the problem from how to minimize the size of the flooded surface to how to minimize the amount of time that land is underwater. This reframing made it possible for the civil engineers and the researchers to explore a different range of technical options. Engineers abandoned the idea of a flood retention basin, which would have led to a permanent loss of arable land. Instead, they decided to use the farmland as a retention area and provide a system to drain the flood water. This option made it possible to recreate a wetland using a larger area of farmland that had been initially reserved for the retention basin. The solution served both ecological and flood protection purposes. Although existing farming activities on these surfaces would not be possible anymore, farmers would still own the land and benefit from direct payments for ecological services from the Swiss federal government.

Using the example described above, Table 3 shows how the framework could be filled out for the first row (the "Plurality of perspectives and interests" aspect of complexity). For the "What" column, the description can include the number and backgrounds of the project participants, the balance of power between them, the mood of the meetings, what the differences are in interests, etc. In the case of the restoration project presented above, participants were associated to different priorities in governing and regulating the hydro-ecological system.

For the "How" column, the interests of key actors in the restoration project are described. We noticed upon reflection, however, that while state officers, engineers and ecologists explicitly mentioned their interest to us either in formal interviews or during informal conversation, this direct exchange never occurred with farmers. We initially assumed that individual farmers' interests would be aligned with the official position of a farmers' union. We did not question our initial assumption because it seemed to be shared by all others implicated in the project. Local farmers never had been explicitly asked to state their interests, until opposition to the initial project plans arose from their side.

For the "Insights" column, we realized that we assumed that the official position of the farmers' union represented the opinion of all individual local farmers. This turned out not to be the case. The famers' union wanted to minimize the

Table 3 Heuristics framework for joint problem framing

The "What" - Guiding questions linked to key challenges of JPF Note down your initial impressions.	**The "How" - How do you know what you described in the previous column?** Please recall specific instances and observations.	**Insights – What was something surprising that you learned from reflecting on columns 1 and 2, if any?**	**Lessons learned – How might you be able to apply the insights to future processes?**
Challenges related to complexity			
Plurality of perspectives and interests			
What were/are the different interests and perspectives present in the JPF process? *State officers of the Canton of Geneva want to have a technical solution to flood protection that is in line with national regulation and accepted by all parties* *Engineers hired to do the project just want a project to be done.* *Ecologists want to preserve the current ecosystem.* *Farmers want to give away as little land as possible.*	*Possible prompts:* • Did all involved actors express their interests equally? • On what basis were the interests of the different actors identified? *State officers, engineers and ecologists explicitly mentioned their interest in relationship to the project either in formal interviews or during informal conversation, but we initially assumed that the farmers interests were aligned with the official position of a farmers' union. We, along with other actors, also referred to this opinion as representative of local farmers' position. We did not question our initial assumption because it seemed to be shared among all actors implicated in the project. Farmers were never explicitly asked to state their interests, until they opposed to the initial project plans.*	*We assumed that the official position of the farmers' union represented the opinion of all individual local farmers. However, this turned out not to be the case. The famers' union wanted to minimise the surface of arable land impacted by the project, based on the mental model that land impacted by the project was lost agricultural land. The farmers, on the other hand, knew that floods did not affect their activity provided the flooding lasted less than 3 day. They therefore wanted to minimise the duration of the flooding period, regardless of the amount of area that would be flooded.*	*Do not rely on assumptions about "typical" interests of some categories of actors because they may be misleading. A non-explicitly stated interest might not be the actual interests.* *Explicitly ask (maybe individually) stakeholders about their interests;* *Triangulate the validity of an expressed/ assumed interest through various mediums (archives, newspapers, etc.) and other people.*
Access to knowledge			
What is the basis of knowledge that actors relied upon during the JPF process?	*Possible prompts:* • Did the actors explicitly make reference to scientific studies they saw as relevant to understand the local situation? • Did they argue using numbers and figures, refer to personal place-based knowledge or • refer to things said by other actors?		
Unstructured information			
What were the sources of information and data that had to be communicated and negotiated between participants?	Possible prompts: • Did all the actors seem to understand the provided information? • Were there misunderstandings among actors?		
Dynamic change			
What were the expected and unexpected changes that happened during the JPF session(s)?	Possible prompts: • Was any event mentioned as a perturbation that changed the planned course of event? • Was there any comment or contestation about the inclusion of new actors? • Was there any comment about a change of position of some actors? • Was there any point in the process when it appeared that some important information had been overlooked?		
Unforeseen linkages			
What were unforeseen linkages that appeared during the JPF process?	Possible prompts: • Was there any mention of something appearing as surprising/unexpected? • Was there any demand to integrate a new type of knowledge? • Was there any demand to include a topic/actor/area that was not initially integrated to the project?		
Process-oriented challenges			
Quality of interactions			
What actions were intentionally or unintentionally taken during the JPF process to enable good quality interactions during the JFP process? What were the effects of taking these actions?	Possible prompts: • Did the composition of the TD research team enable to discuss all relevant aspects of the problem? • Was the interaction between participants enabled? • Could all actors voice concerns or questions? • Was the setting interactive? • Did any participant voice concern about the process?		
Knowing and accessing concrete methods			
What concrete methods (if any) were used intentionally for the JPF process? What were the effects of these methods?	Possible prompts: • Did participants recognize the benefits of using structured methods? • Did the methods enable to formulate problems that were not seen before? • Did then methods generate new knowledge among participants? (aha effect) • Did the methods allow better mutual understanding among participants?		
Available resources for fostering collaboration			
What resources (e.g., time, funding, etc.) were available for conducting the JPF process?	Possible prompts: • Was the availability of any resource underlined by some actors as instrumental for the project? • Was the lack of some resource seen as problematic by some participants? • Did I feel that there were insufficient resources for the project?		

surface of arable land impacted by the project, based on the mental model that all surfaces impacted by the project were not arable land anymore and, therefore, a loss for agriculture. The farmers, on the other hand, did not mind having their land used for flood management, provided the floods did not last for more than 3 days. Moreover, they did not consider the land used for the wetland restoration as loss for agriculture, as they continued to own these surfaces and received direct payments for the ecological services they provided.

The "Lessons learned" from this example was that we should not rely on assumptions about "typical" interests of some categories of actors because they may be misleading. A non-explicitly stated interest might not be the actual interests. It may be a good idea to explicitly ask (maybe individually) stakeholders about their interests. We could, for example, triangulate the validity of an expressed/assumed interest through various mediums (archives, newspapers, etc.) and other people.

Discussion

The framework does not present a definitive, fixed set of questions for conducting a JPF process. Rather, the questions serve as a checklist reminder of possible important factors to consider when engaging in a JPF process with a complex problem at hand. It serves as a type of "pattern language" (Alexander 1977) for creating one's own context-specific questions. Not all categories of questions may be equally relevant to all contexts. The aim of the framework is to draw awareness to the consequences of one's own or others' behaviours in specific situations of JPF and to consciously learn from these experiences. The framework is intended for any researcher who engages in a transdisciplinary process with participants with diverse interests and perspectives, where specific problems and goals for a project where goals have yet to be defined. Its use is not restricted to any particular topic or discipline. Originally, the motivation for such a framework was to develop a tool that could help less experienced researchers in the field of transdisciplinary work to build reflexivity in a concrete way. This framework could be used, for example, as a training tool for Master's or Ph.D. students engaged in their first projects. In our experience of teaching and supervising, we find that many students are uncertain about whether they are "doing" transdisciplinary research "right". However, we see the potential of using such an approach, also for experienced researchers, who would like to capture the tacit knowledge they have already acquired.

In this way, tacit knowledge acquired within a project can be adapted for future processes, reducing the need to reinvent the wheel for skills which are not cultivated in universities, but needed for the real world. In addition, it might be possible to discuss and to enrich individual perspectives of the tacit knowledge. For instance, researchers on the same project can compare their answers to the questions in the framework. In this way, team members may be able to gather the full spectrum of possibilities for how to engage in an effective JPF process.

The framework could be filled out at various points of a project lifecycle, either during or after the process. It may be that the "Lessons learned" from one project can only be implemented in a future project. If used early enough in the process or if there is sufficient time dedicated to the JPF process, it might be possible to adapt the lessons learned in the same project. Since the answers to the questions given in the framework rely on detailed observations or recollections of what happened, it may be difficult to recall such details for a past project that was not well documented. When using the framework for a present project, it may be a good idea to review the questions before going into a meeting or workshop where JPF might take place, to direct one's awareness to what happens in the event. It may also be useful to fill out the table soon after each meeting of a project, and then to compare how one's understanding and observations have evolved over time.

Conclusion and future research

JPF is an essential, yet challenging process in transdisciplinary research. There has not been much guidance available in the academic literature regarding how to conduct effective JPF processes in the field. We draw out what these actions might be through identifying challenges to problem framing that have been identified in the literature. By delineating these challenges in concrete terms, we hope that they could be further discussed and other solutions might be found to tackle them. We have conceived of challenges both in terms of the aspects of complexity inherent to the problem itself and the practical challenges that researchers face when engaged with the JPF process. We translate these actions into a framework of questions to help researchers reflect upon observations, explanations and assumptions of what occurs during the process, to build up and make knowledge explicit for improving problem framing process for future projects.

What remains to be done in the future is to test the effectiveness of this framework within specific transdisciplinary projects. Given this feedback, it may be possible improve the quality of prompts in the framework. It may also be fruitful to develop a version of the framework that is specifically for practitioners who work outside of academia as a way of exchanging different perspectives on what is happening in a project. In addition, this heuristic approach might also be adapted to other stages of transdisciplinary research, for

example, the co-production of knowledge, implementation of results or other stages of transformation where diverse viewpoints need to be taken into account.

We hope that this framework can provide a means for cultivating reflexive practice directed towards JPF. We hope that it contributes to a deeper understanding of the process in transdisciplinary research and the development of future transdisciplinarians.

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