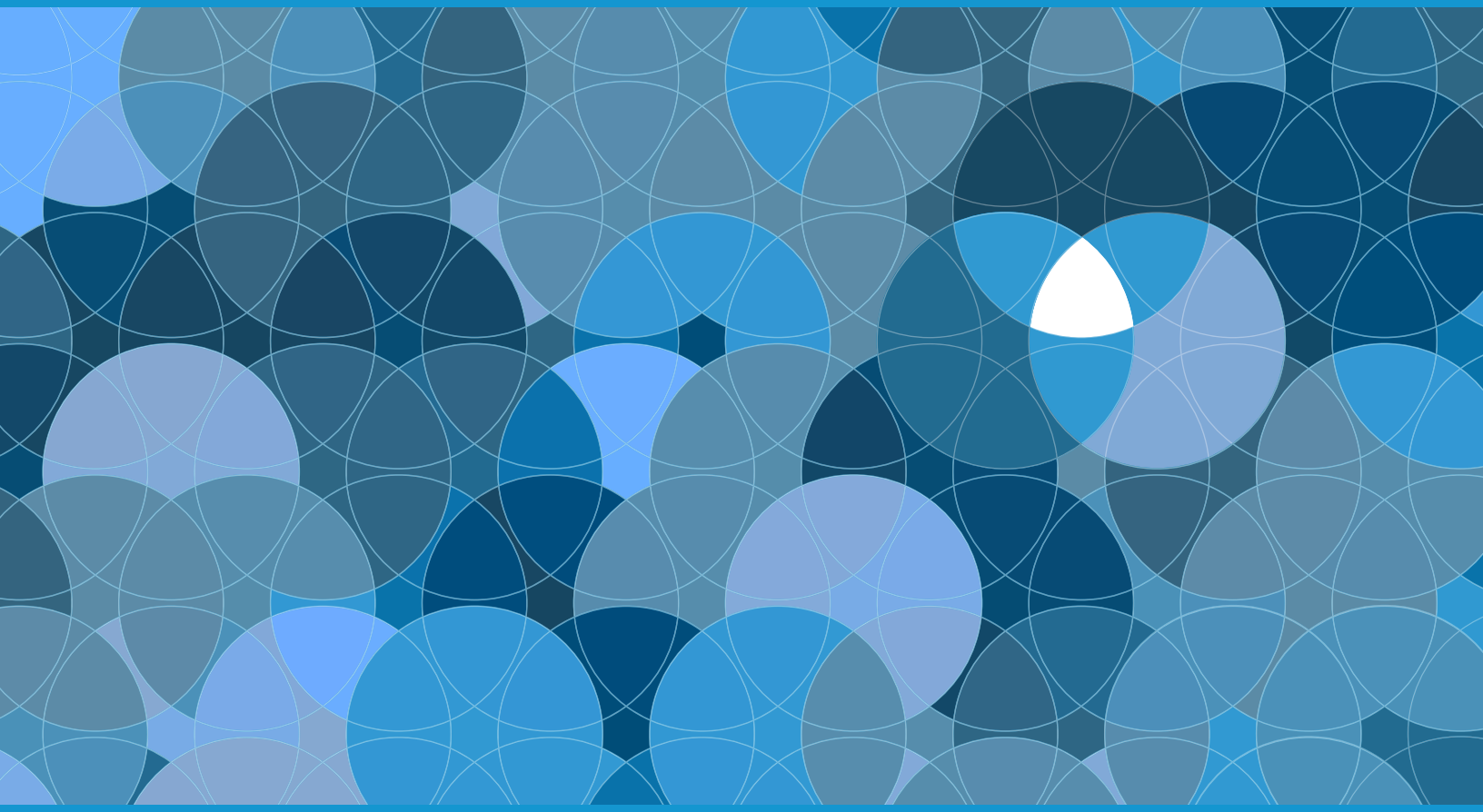
Handbook of Interdisciplinarity

(CR)2 Dialogue and Interdisciplinarity Area



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(CR)2 Center for Climate and Resilience Research

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(CR)² Center for Climate and Resilience Research

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Why prepare a Handbook of Interdisciplinarity?

The current ways that science is structured, and its results evaluated are intersected by the complexity of the challenges facing our society. Complex or 'wicked' problems, such as those generally known as 'development issues' (such as inequity, overextraction of natural resources and the impacts of climate change), have prompted the scientific community to revisit and transform the boundaries of their disciplines and move towards questions, methodologies and approaches that are increasingly integrated and based upon the society's needs (Hessels & Van Lente, 2008). The complexity of present-day problems thus presents new scientific challenges and demands changes in the process of knowledge construction. This translates into new scientific approaches that, among other challenges, seek to go beyond conventional disciplinary and institutional structures of knowledge generation (Stanley et al., 1988; Allmendinger, 2015; Urquiza et al., 2018).

Reaching beyond disciplinary and institutional boundaries to further science that is focused on problems that are complex and need to be understood and approached in a way that is meaningful for society, however, does not mean we need to leave behind curiosity-based science or disciplinary knowledge. On the contrary, it invites disciplines to stretch beyond their own limits as they produce science and to work collaboratively to construct new knowledge. And that knowledge should not only contribute to climate science, but also should address the sustainability crisis (Brandt et al., 2013). Achieving this will present challenges. However, "in many ways, disciplines are socially constructed conventions that have their own institutional and ideological structures" (Bruun et al., 2005), and thus can be restructured (Frank et al., 1988).

In this context of complex problems whose understanding requires robust scientific evidence, interdisciplinarity emerges as an effective way forward, as it enables the integration of a wider range of competencies and knowledge, while also encouraging coordinated work among different disciplinary, organizational, and socio-cultural spheres (Boon et al., 2014; Klein, 2004; The Royal Society, 2016; Urquiza et al., 2018). In other words, what interdisciplinarity does is seek integration and deep reflection that complexifies existing disciplinary knowledge, in order to offer interconnected answers and solutions to problems that are multi-dimensional, involve diverse stakeholders, and present an array of possible approaches.[1]

Since its creation in 2013, the Center for Climate Science and Resilience (CR)2 has made major strides in fostering interdisciplinary research, at the structural, conceptual and methodological levels. In the framework of (CR)2's purpose—to deepen our understanding of climate change systems, processes and impacts in Chile—dialogue among disciplines becomes a mission in itself, and one of the cornerstones of the Center.

As illustrated below in an excerpt from a thesis investigation conducted in 2020 and using (CR)2 as a case study, for a significant proportion of researchers, interdisciplinarity is one of the Center's hallmarks, while at the same time being a feature that distinguishes it from other research centers.

1 Interdisciplinary work has been used in different fields and spheres. Examples can be found in the fields of health, urban planning, education, and architecture, among others (Lawrence, 2015; Lawrence and Després, 2004). It has been especially prevalent in environmental science, as in this sphere the search for solutions involves a broader range of knowledge and competencies (Klein, 2004; The Royal Society, 2016; Boon et al., 2014). Interdisciplinary work has been useful in the environmental sphere, for example, in creating adaptation plans, defining guidelines for risk and disaster reduction programs, establishing institutions that synthesize scientific evidence for decision makers and other uses (Brandt et al., 2013; Lynch et al., 2015; Lawrence, 2015; The Royal Society, 2016).

> "Interdisciplinarity flows from the institution and the practices and aspirations of the investigators; it is present in their conversations and in their reflections and is a topic of mutual interest. At the same time, the Center provides a set of conditions, such as meetings, communication networks and group dynamics to make the interdisciplinary work as fluid as possible. This is one of the factors in this research center's success and fruitfulness, and situates it at the cutting edge of science in Chile. Knowledge production at (CR)2 occurs in this environment, an interdisciplinary atmosphere." (Aguirre, 2020: 47).

However, we still have some way to go. Interdisciplinarity still presents major challenges, on the one hand related to the need to instill the practice throughout the investigative process, from the formulation of the research question to the written scientific product; and on the other, to overcoming the individual and structural gaps and barriers that still hinder interdisciplinary work. These include language differences; investigator workload;[2] the need to reconcile researchers' lack of time and heavy workload with the extra effort required to conduct interdisciplinary research; the imbalance of human capital that exists at the Center (mainly the dearth of social science disciplines represented); and the low value placed on interdisciplinarity in the structuring of scientific skills and assessment systems, among other aspects.

This Manual presents (CR)2's experience with interdisciplinarity and we hope it can serve as a tool to build more bridges between disciplines represented at (CR)2, while at the same time closing the gaps and overcoming the barriers that still hinder their integration. This handbook is the result of a review of the scientific literature,[3] observations documented by different work teams and meetings held at (CR)2 over the past two years.[4] Its aim is to provide specific tools to facilitate interdisciplinary work, covering at least the methodologies and collaborative disposition that must be addressed at the different scales of work conducted at the Center (individual, collective and organizational). More specifically, this handbook is intended to:

1. Raise awareness of (CR)2's interdisciplinary experience; the efforts made and the obstacles that still have to be overcome.
2. Demonstrate, on the basis of (CR)2's experience, the need to adopt certain principles (individual and collective) to further interdisciplinary work.
3. Provide conceptual and methodological tools for undertaking an interdisciplinary project or investigation, and highlight the need for follow up and evaluation.
4. Contribute to building bridges and closing gaps among the Center's disciplines, to promote greater interaction and more effective collaboration.

All of the above will ultimately help to better our understanding of the processes and impacts of the

2 The academic activity of (CR)2 investigators (and scientists in general) is comprised of multiple commitments and responsibilities within and beyond the Center. Except for full-time investigators and post-doctoral researchers, for the majority of (CR)2's researchers, the center is their secondary scientific venue (the first being the universities affiliated with the Center). This sets up a barrier to interdisciplinary work, in the sense that it makes it difficult to dedicate the time necessary for collective reflection and the search for methodologies that facilitate and put into practice disciplinary synergies.

3 A review of 85 scientific articles was conducted, 32 of which were used in the preparation of this handbook. In doing so, filters were used that took into account theoretical-conceptual fields, practical applications, methodologies used and ways of evaluating interdisciplinary work.

4 More specifically, the sources examined were 56 internal records: field notes and records of extended meetings, line meetings, work sessions on integrative themes, in-house workshops held from 2018 to 2020, as well as organizational documents (2016 organizational analysis, institutional reports, research line work proposals, organizational sustainability plans and research-in-progress and management presentations) prepared between 2015 and 2020.

climate system in Chile while meeting the challenges we face in achieving sustainable development and our commitments under related international agreements.

Interdisciplinarity at (CR)2

Within CR(2)'s work and research objectives, we can identify three *drivers* that have favored the development of interdisciplinarity at (CR)2. These are:

1. *Climate change science*: The Center's focus on investigating the causes and effects of climate change, which are complex in nature, necessitates a shift toward integrated questions and approaches.
2. *Interdisciplinary grouping*: The participation of researchers from different disciplinary backgrounds is one of the principles upon which (CR)2 was founded. In other words, it is an essential part of the Center. To this end, (CR)2 brings together researchers from different natural and social science disciplines, making different approaches, methodologies and research questions available to foster greater understanding of the causes and effects of climate change.[5]
3. *Science-policy and science-society interfaces*: The Center's work involves ongoing interaction with different stakeholders in the public sector and the broader society on issues related to climate change, to contribute to public policymaking and developing greater social resilience. This orientation favors interdisciplinary work in at least two ways: On the one hand, these interactions have enabled (CR)2 to ask questions and identify challenges (related to CC) that can only be addressed with an interdisciplinary vision. Second, the challenge of communicating the scientific evidence produced in ways that can effectively impact different stakeholders, motivates us to find formats and languages that are comprehensible and tailored to different audiences.[6]

Still, although these *drivers* undoubtedly favor interdisciplinarity, achieving it is not automatic; on the contrary, it takes time and effort to instill interdisciplinarity in the minds and practices of those who would work in this way.

Moving towards interdisciplinarity has involved some major changes and initiatives at (CR)2. One of the greatest changes has been structural. As the second stage commenced at CR(2) in 2018, our lines of investigation were reformulated; instead of working along disciplinary lines, we now work to common questions or themes, each of them complex issues,[7] giving rise to the configuration of general interdisciplinary teams.[8] One researcher

5 This driver is also related to the fact that interdisciplinarity is a requirement of ANID (Chilean National Research and Development Agency) for FONDAP-funded centers and one of the criteria upon which the center is evaluated each year.

6 To the degree that both involve work among stakeholders from different sectors or spheres (academic, public and private sectors, and/or civil society), the terms "interface" and "transdisciplinarity" are occasionally used interchangeably. However, the literature clarifies the differences between them. An interface could be defined as a shared area or place for meeting and interaction among stakeholders from different spheres or sectors. As such, we speak of the science-policy and science-society interface, as well as of others (public-private, urban-rural, among others). As for transdisciplinarity, there is a general (albeit not absolute) consensus in the literature that its central purpose is to integrate different forms of knowledge, and thus putting it into practice involves a collaborative methodological process and approach to the work. Thus, a science-policy or science-society interface can exist without it necessarily being transdisciplinary. Transdisciplinarity necessarily involves the integration of knowledge and/or the active search for integrated methodologies.

7 These are: Water and Extremes, Land Use Changes, Resilient Cities, Governance and Science-policy Interface, and Coastal Zone.

8 Nevertheless, the configuration of research lines does not follow a set pattern in regard to the natural vs. social science

from the natural sciences and one from the social sciences take on the roles of principal investigator and principal co-investigator. Added to this, we have created and implemented integrative themes as investigations that are conducted in parallel to our lines of investigation and whose objective is to take an integrative approach to addressing issues pertinent to climate change in Chile, with emphasis on supporting public policymaking.[9] This work within our lines of investigation and integrative themes is not free from difficulties, above all considering the major imbalance that remains between investigators in the natural sciences and those in the social sciences.[10]

A second aspect of moving towards interdisciplinarity is reflected in the introduction of work methodologies that favor this kind of work within and among (CR)2's different lines of investigation. The Governance and Science-policy Interface line[11] and investigators in the social science disciplines[12] have made major strides in this regard, as has the Dialogue and Interdisciplinarity area (since 2018), which, like the reformulation of research lines, was created to ensure the Center's ongoing sustainability (see the workstreams in the Dialogue and Interdisciplinarity area in Annex 1).

Hand in hand with its methodological efforts, the Center has also undertaken theoretical-conceptual work.[13] On the one hand, a review of the specialized literature has brought to light different definitions of the concept of interdisciplinarity, along with the concepts of multidisciplinarity and transdisciplinarity that often accompany it. As Figure 1 shows, in regard to these terms, some authors focus on the number of disciplines and stakeholders involved (Tress et al., 2005; Klein, 2010), others on the type of problem being addressed (Klein, 2008), still others on the methodology used (Bracken and Oughton, 2006; Raymond et al., 2010), and yet others on the results of the investigative process and knowledge generated (Tress et al., 2005; Sanz-Menéndez et al., 2001; Lynch et al., 2015).

The specialized literature review has also enabled us to identify certain elements that are common

balance - i.e.: the Governance and science-policy interface line is comprised primarily of social science researchers and the Water and Extremes line is comprised mainly of natural science investigators.

9 Integrative themes were first implemented in 2018 as part of (CR)2's stage two. Unlike the Center's lines of investigation, integrative themes have a duration of 2.5 years, and in addition to scientific deliverables (articles, books and book chapters), consider "report to the nations"-type deliverables that summarize the state of the science and serve as relevant, accessible input for formulating public policies. The integrative themes proposed in the (CR)2 continuity plan are: Air Pollution, led by the Cities line; Forest Fires, led by the Land Use Change line; Water Security, led by the Water and Extremes line; and Harmful Algal Blooms, led by the Coastal Zone line. In 2020, development of the new integrative theme on Climate Governance of the Elements was launched at the Center, led by the Governance and Science-Policy Interface line.

10 The number of investigators in the social, legal and economic sciences affiliated with (CR)2 is still quite low compared to those in the physical and biological sciences. This is an obstacle for interdisciplinarity and creates an undue workload for social scientists, as they must invest extra time to meet the requirements of the Center's interdisciplinary approach.

11 In 2018, the Governance line held two internal workshops: the first to create a shared conceptual understanding of the term climate change governance, the second to reflect together on the role of the expert in climate change governance. These sessions marked a milestone in the Center's interdisciplinary work, as they gave rise to a shared theoretical reflection, greater understanding among peers, and therefore more openness to learning about different disciplinary structures.

12 Before stage two began, these were part of the Human Dimension line.

13 Despite its importance for addressing complex problems, interdisciplinarity has itself become a "problem" that is addressed by several approaches and authors (Guggenheim, 2006; Klein 2008, 2010; Borrego and Newswander, 2010; Barton et al., 2015; Huutoniemi et al., 2016; The Royal Society, 2016; Urquiza et al., 2018). Because of this, in the specialized literature there are a variety of definitions for the term "interdisciplinarity", as well as for the notions of "multidisciplinarity" and "transdisciplinarity". This also produces a certain confusion in the use of these terms and/or in their indiscriminate use in the different spheres that employ an interdisciplinary approach.

Figure 1: Approaches to interdisciplinarity

Type of knowledge	Monodisciplinary	Multidisciplinary	Interdisciplinary	Transdisciplinary
Stakeholder involved	Single scientific discipline	Stakeholders from different scientific disciplines	Stakeholders from different scientific disciplines	Academic, public, private and civil society stakeholders
Problem	Problem is centered	Complex problem: a scientific question or problem not specific to a single discipline that requires more than one discipline to address it	Complex problem: a scientific question or problem not specific to a single discipline that requires more than one discipline to address it	Social question or problem (political, economic, educational, health-related, etc.) that requires the generation of robust social-scientific knowledge (i.e. knowledge that takes into account non-academic stakeholder perspectives)
Methodology		Methodologies from each discipline are maintained	An interdisciplinary methodology is proposed	Participatory methodologies for integrating different types of knowledge (*knowledge dialogues*)
Knowledge generated	Disciplinary knowledge	Sum of disciplinary knowledge	Coordination of knowledge foundations	Integration of different types of knowledge

Source: Paper in progress (Amigo, C; Morales, B.; Muñoz, C.; Neira, I.; Urquiza, A.)

to different approaches and are crucial for implementing collaborative processes that require the participation of different scientific disciplines (and different kinds of knowledge). First, moving from one approach to another, i.e. from multidisciplinarity to interdisciplinarity, and from there to transdisciplinarity, implies progressively more integration of disciplinary frameworks (at the methodological and conceptual levels and in terms of the knowledge generated). In other words, interdisciplinarity evolves into progressively deeper levels, and thus can operate at an initial, intermediate or advanced stage. Second, all approaches include the idea of coordination and/or dialogue among disciplines, and/or between disciplines and other social spheres (in the case of transdisciplinarity). This means that scientific know-how is situated in a space that requires reflexive, dialogical coordination[14] (Brandt et al., 2013; Lawrence, 2015; Urquiza et al., 2018), and that in turn allows the process to evolve beyond disciplinary boundaries to generate robust scientific knowledge.

Thus, in its most comprehensive definition, interdisciplinarity can be understood as "the collaboration among actors in different scientific disciplines, who attempt to respond to a question or address a problem that is not exclusive to a particular field, and in which methodological and conceptual integration results in scientific knowledge that would not have been achieved without that coordinated effort." Interdisciplinarity also must be distinguished from transdisciplinarity, in that the latter involves collaborative work between science and society, meaning that it involves access to other sources of

14 Taking into account what different authors have proposed, "reflexive, dialogical coordination" refers to the need, above all when addressing a complex problem, to ensure that scientific knowledge (and knowledge that is generated in the science-society interface) is generated in participatory instances, through dialogue that facilitates greater reflexiveness among different stakeholders and disciplines.

knowledge outside of the strictly scientific sphere,[15] and therefore, is thought of as a more ambitious approach than interdisciplinary work.[16]

A fourth push made to advance interdisciplinary work at the Center is reflected in the products we generate, and involves two major initiatives. First, (CR)2 has striven to construct scientific products in which physical, biophysical and social information have been brought into dialogue effectively. This has led to discussions about traditional formats that are deeply rooted in the academic world in Chile and abroad. Furthermore, the need to convey scientific research in products tailored for other audiences (especially decision makers) has led (CR)2 to focus on products that offer simplified, attractive formats.[17] This itself requires constant reflection and careful nuancing of the rhetoric of each discipline active at the Center if we are to convey that evidence meaningfully in our products and contexts. Examples of these are 'reports to the nation', our 'policy briefs', 'climate capsules' and climate databases.[18]

A fifth and final effort is related to the need to monitor interdisciplinary practice. In the past two years, the (CR)2 has worked hard to document and monitor the Center's interdisciplinary research experience, from both qualitative and quantitative perspectives. Qualitatively, this monitoring has involved identifying and raising awareness of shared values and practices that exist in the sphere of interdisciplinarity, as well as the obstacles that still hinder interdisciplinary work. From a quantitative perspective, monitoring interdisciplinarity has focused on gathering information on the different disciplines present at (CR)2 (according to OECD and Web of Science categories) and their relative representation in terms of the number of investigators working with the Center; the number of interdisciplinary scientific publications[19] accredited to (CR)2 (since 2013); and the frequency of interaction among different disciplines.

The principles of interdisciplinary work

One of the central obstacles researchers face in interdisciplinary work is the perception that engaging in the co-creation of knowledge detracts from disciplinary knowledge. As mentioned above, interdisciplinary work seeks to achieve deep integration and reflection that complexifies existing disciplinary knowledge, to foster understanding and further the search for interconnected solutions to problems that require robust scientific evidence. In other words, interdisciplinarity seeks to extract the best of each discipline and make it available in a research and learning process focused on a shared objective and/or product that requires this kind of approach. To achieve the last of these, the researcher's willingness and availability to collaborate with others (disciplines, knowledge, spheres of knowledge) is a crucial aspect.

Recently, the Center organized a dialogue among academics from the Universidad de Chile, the main objective of which was to offer an opportunity for reflection on the concept of transdisciplinarity, as it applies to the university's research, outreach and pedagogical projects (Urquiza et al., 2019). From this work, the team identified three ways of 'openness', or transversal considerations, that are crucial for

15 Namely, "traditional," "local" and "informal" knowledge (i.e. "non-scientific").

16 There are authors who, in contrast, define the three terms (multidisciplinarity, interdisciplinarity and transdisciplinarity) within the sphere of science, meaning all three refer to collaborative work among scientific disciplines (with differing degrees of integration), with transdisciplinarity being the moment at which disciplinary boundaries disappear.

17 In constructing these products, the work of (CR)2's Communications area and Data and Computing area has played a central role.

18 The Center's webpage (www.cr2.cl) offers examples of each of these products.

19 Interdisciplinary publications are understood as scientific articles or products authored by two or more (CR)2 investigators in different disciplinary categories.

beginning to overcome individual and institutional barriers that hinder progress towards interdisciplinarity. These are:

- Epistemic openness: This refers to the mutual respect among knowledges that values collaboration between the different positions they are based on.
- Theoretical openness: Which means being aware of one's disciplinary assumptions and premises about the object of investigation, and therefore being open to discussing them.
- Methodological openness: Which invites us to question how we produce our own knowledge, its relevance, and how potentially accessible it is to the broader society.

Our experience at (CR)2 has also enabled us to identify certain principles that can complement these forms of openness, and should be reviewed before initiating an interdisciplinary project or investigation. In light of this, the abovementioned complementary principles are:

Willingness to cooperate and learn

> "I believe that interdisciplinarity begins when we are able to convey ideas, speaking different languages, using different concepts, and that is where inspiration springs from. I believe that is a key to cultivating creative, original science." (Investigator, (CR)2 plenary meeting, January 2021)

While this could be understood as a researcher's willingness at a given moment and time, this principle is actually more about the conscious, regular practice of attempting to delve into disciplinary and social spaces that one is not accustomed to visiting. For a large number of researchers, the process of dialogue with other disciplines is an ongoing learning experience, one that has enabled them to escape from their own disciplinary lens and open themselves to building a much broader perspective and, in some cases, to participate in the creation of shared languages.

Scientific curiosity is a good driver of this principle, but it is not enough. The Center's experience shows that to achieve this orientation, motivation is crucial, in the sense of learning or witnessing that cooperating with others leads to new knowledge that is more encompassing. To instill this principle, it is also essential to create spaces that enable us to discuss and communicate the science, present our scientific advances, share the results of our investigations, captivate and allow ourselves to be captivated.

At (CR)2, our plenary meetings are one of our most important instances, not only for divulging our science, but also for getting to know and interacting with disciplines other than our own. Our plenary meetings offer the opportunity for our investigators to focus on a single objective and task. They are a space of "timeless time" in which investigators can immerse themselves in a space shielded from external demands and pressures (Ylijoki & Mäntylä, in Lynch et al., 2015), and in which it is also possible to deliberately plan opportunities for collective pauses and relaxation that, as we will see below, also favor interdisciplinarity.

Lastly, to foster a willingness to dialogue and learn, it is also important to dare to ask the most fundamental questions about epistemological, theoretical, and methodologically 'distant' disciplines. This not only helps the researcher who poses the questions; it also encourages the pursuit of other languages and ways of making knowledge accessible and appeals to the communicative creativity of the person who is being asked to explain.

Co-presence and reflection

Co-presence is the act of being present in a shared instance. This can occur to a greater or lesser degree, according to the available material, technological, temporal, and human resources (will, interests,

commitment). This is one of the most challenging yet important principles, given our current attachment to multitasking (answering emails and text messages, working on one's own presentation while another colleague presents their scientific evidence, etc.). In an interdisciplinary project or study, the researchers have to find mechanisms to prevent multitasking during work meetings, workshops and other important gatherings intended for knowledge generation, and work towards instilling active listening habits.

The will to engage in attentive, active listening also should be cultivated as a habit, as it is likely to contribute to scientific reflection in general and interdisciplinary work in particular; it can also offer a space for reflection, encouraging the recognition of common points, as well as divergent ones, among disciplines.

Willingness to shift disciplinary boundaries

> "–We tested and applied existing models from atmospheric sciences to obtain behaviors and qualities of certain phenomena. So, we're going from the quantitative to the qualitative.
>
> –Right, the opposite is true from a social science lens. We compiled qualities based on observing the social phenomenon and based on that (and depending on the objective and the sample) we obtained the "representative numbers"[20] (Conversation among members of RedLama)[21]

Another barrier that often hinders interdisciplinary work is the hyper specialization of language and concepts within each discipline. This has consequences in different spheres and stages of interdisciplinary work. First, it makes it hard for other scientists to comprehend information; and second, this in turn causes researchers (and others involved) to self-exclude themselves from participating, as they have not mastered the codes of the discipline in question, which leads to questions such as: "*What can I contribute here?*" or "*I can't see how I can contribute.*"

To overcome this barrier, our third and final principle is important: the willingness to shift disciplinary boundaries, meaning to reflect on the investigative context in which we are operating and make explicit the differences that exist among disciplines, not only at the epistemological level (how we know) and in terms of language (how we communicate), but also in methodological terms (differences in ways of collecting and analyzing information).

Disciplinary boundaries can be moved in at least two directions: first, within the discipline itself; for example, identifying those concepts used in the discipline itself that are unknown in other disciplinary environments, or are defined differently, which can lead to confusion in the context of interdisciplinary work. One interesting example of this that has come up at (CR)2 is the definition that is given to the term 'community' in the social sciences compared to how it is used in the biological sciences.

Second, shifting the boundaries invites one to engage in the practice of familiarizing oneself with other disciplines. The process of interdisciplinary coordination inevitably involves learning about tools from other disciplines, and for this the researcher must learn about and connect first hand with languages and conceptual approaches outside of their own field, and understand that the methodologies and variables analyzed require different investigate timeframes, data sets and analyses.

Reflecting on the boundaries and strengths of

20 This quote does not intend to imply that the scientific exercise outlined can be generalized, but rather to provide one example of the kind of reflexive process that can emerge during interdisciplinary work.

21 RedLama is a network of young scientists that includes undergraduate, masters' and Ph.D. students working at the Center for Climate and Resilience Research (CR)2. Its purpose is to convey to the public the knowledge produced at (CR)2, emphasizing the educational sphere and accompanying the school community and the general public in constructing knowledge about environmental and climate change sciences.

one's own and other disciplines offers a window of opportunity for generating scientific answers and proposing more robust solutions to the research questions that emerge from the complex problems that today's society faces.

Practical tools for strengthening interdisciplinary work

> "...nurture heterogeneity and diversity in terms of knowledge, organizations, etc. but at the same time create a univocal product" (Boon et al., 2014)

How do we do interdisciplinary work? is perhaps one of the most commonly heard questions among researchers at (CR)2 when, in the framework of different investigations conducted on the causes and effects of climate change, the need to work with other disciplines becomes evident. We have developed a series of methodological lines at the Center that, we believe, can strengthen interdisciplinary work, and we have incorporated them into this handbook.

These lines can be presented as two broad lessons learned that, like the above-mentioned principles, are important to keep in mind when embarking on a research project that requires an interdisciplinary approach.

The first lesson is related to the idea of *process*. More than a result, interdisciplinarity should be understood as a critical, reflexive learning process in which each stage is carried out in a thoughtful way, so it is nourished not only by the data, information and evidence from the different disciplines involved, but also by reflections on the scientific practice itself. This also enables disciplinary objectives, concepts, scales, methods and practices to be reformulated. In similar fashion, other benefits accrue, in the process of careful planning, such as trust building and forming work partnerships, which are also crucial for the success of the investigation.

The second lesson learned relates to the idea of *dialogue*; in other words, beyond the aggregation of content, what is important in the context of interdisciplinary work is that the researchers dialogue with each other to understand, foster understanding and address a complex problem. In this sense, all interdisciplinary work methods should be built on the foundation of coordinated dialogue (Brandt et al., 2013; Lawrence, 2015; Urquiza et al., 2018) among the different disciplinary knowledges involved, and the effort put into that dialogue should be greater the further apart the disciplines are (between physical and social science disciplines, for example).

The methodological guidelines presented below are focused on three critical aspects of the investigative process, namely, the design stage of an interdisciplinary project; the design and implementation of *ad hoc* meeting spaces used to address the challenges of interdisciplinary work; and the way researchers can measure advances in interdisciplinary work.

Project design

In the context of an interdisciplinary project, special attention should be paid to the design stage. This goes beyond formulating a shared response to a complex problem that requires knowledge from different disciplines and the 'guiding thread' usually employed in a scientific research project; because an interdisciplinary research project is precisely one that has as many approaches to its implementation as it does disciplines that are present.

As such, the methodological strategies to be used in the project must be planned carefully, so they facilitate and direct key aspects of the investigation.

Participatory design of research questions and objectives

As with any single discipline investigation, the first step in a multidisciplinary project or investigation is to define "what are we going to study?" or, more concretely, "what is the problem to be addressed?"

However, unlike classic project design methodologies, defining the questions and objectives

that will guide an interdisciplinary investigation requires a participatory process. In this process, the contributions from each discipline involved should be made explicit in the research question, in the overall objective and across the specific objectives.

For example, the integrative themes established for 2020 at (CR)2 —Water Security Integrative Theme (*tema integrativo de seguridad hídrica*, TISHi) and the Harmful Algal Blooms Integrative Theme (*tema integrativo de floraciones algales nocivas*, TI-FAN)—included a 4-month stage to design the scientific proposal. During that time, the research objectives and questions were defined, along with the conceptual framework, the scope and the scale of the investigation. The proposal design process employed a co-constructed participatory, interdisciplinary methodology that included workshops open to the entire (CR)2 community, the use of questionnaires and validation surveys, work meetings among the coordinators of the integrative themes, meetings of the advisory boards (comprised of investigators from the Center's lines of investigation), and meetings with the methodological support team.

In referring to this stage, the TI-FAN coordinators noted:

> "This meant accepting that the process was slower, but had tremendous gains in terms of the quality of the contributions received and the legitimacy of the proposal within (CR)2." (TI-FAN presentation, September 2020)

Examples of methodologies that facilitate co-construction in investigations or projects that require participatory processes include: *participatory workshops*, focused on learning, making explicit the assumptions of those involved and co-constructing potential scenarios (A. Smajgl and J. Ward, 2015, Evaluating participatory research: Framework, methods and implementation results); the *metalogue* methodology (Urquiza et al., 2018, Metálogo como herramienta de colaboración transdisciplinaria), in which one or several opportunities for dialogue are offered in order to reveal the different rationales present in ways a problem is envisioned. A final methodological example is the so-called *Bayesian Networks* (M. Welp et al., 2006, Science-based stakeholder dialogues: theories and tools), which have objectives that are different from exclusively scientific dialogues, or those involving decision makers.

Forming interdisciplinary work teams

One of the pre-requisites to initiating interdisciplinary work is to form interdisciplinary work teams that will work together, strategically, during all stages of the project or investigation. This process is further enriched when not only researchers, but also students and support staff—the entire support network that each researcher relies upon—are involved.

Returning to the above example, once the scientific proposal was designed, the focus turned to forming work teams for the integrative themes. In the case of TISHi, the teams were built around a national perspective and based on case studies that would be used to address water security. For TI-FAN, the teams were formulated along thematic axes defined for studying the causes and impacts of harmful algal blooms. As with the process of reformulating (CR)2's lines of investigation, organizing the work teams based on the themes and/or cases that would be used to respond to the research objectives and questions, is key to ensuring their interdisciplinary makeup.

In both cases, the coordinators extended an open invitation to (CR)2 investigators to join the work teams. Overall, the integrative theme investigations consist of two general coordinators (one from the natural sciences, and one from the social sciences) and four work teams led, in turn, by one or two coordinators each. Each team includes an average of eight to ten investigators, in addition to post-doctoral researchers, undergraduate students and research assistants. In both cases, the work teams were also designed to enable the incorporation of new collaborators and new networks.

In this process, however, it is important when planning and implementing a project to be careful to balance disciplines, in terms of the number of researchers, gender distribution and allocation of roles with greater/lesser responsibility. Along this line, it is also worth identifying leaders whose capabilities make them suitable for group work, who can motivate others, and know how to recognize and promote the strengths of team members. As Molina and Devia comment, "clear definitions of the object or phenomenon to be observed must be combined with constant oversight and reinforcement of the team" (Molina and Devia, 2016:11), so it does not deviate from the interdisciplinary approach.

Thoughts on the 'intermediate stage'

One of the barriers that (CR)2 researchers still come up against when integrating knowledge generated by different disciplines, is the absence of an 'intermediate stage' between formulating the problem and undertaking the investigation. Most agree that, while integration occurs at the stage of constructing the problem, once the investigation begins, it quickly tends to devolve into discipline-centered work.

Hence, the need for this 'intermediate step' after the research problem has been defined. Time needs to be given to designing methodologies that enable knowledge integration. These instances should be set out in the work plan as key milestones in the investigation.

For (CR)2's integrative themes, while each team will define specific objectives, questions and methodologies for gathering and analyzing information for its investigation, each of the themes also designs a methodology for coordinating its work teams. This methodology will enable each team's work to contribute to and remain aligned with the objectives and overall conceptual framework defined for the integrative theme, while also ensuring fluid communication among work teams.

Among other instances, this methodology includes plenary meetings (for each integrative theme), workshops, work meetings and coordination sessions in which each team can report on its progress and the entire group can evaluate how the parts fit together in responding to the problem and fulfilling the investigation's overall objectives. All of this activity is intended to ensure a participatory, interdisciplinary work dynamic.

Building conceptual consensus

In the design stage, it is crucial to identify and define those concepts that will guide the course of the investigation. This is a major challenge as each area, and even each discipline, has its own conceptual framework; this is especially true among more distant disciplines.

In this context, building shared conceptual frameworks becomes indispensable. One effective way this can be done is to collectively build a *glossary*. This exercise seeks to identify points of convergence among different disciplines, but it also allows the team to identify terms that are more controversial, owing to their disparate definitions and entailments. Because of this, reaching consensus must be a flexible process that takes into account this situation.

Recognizing points of convergence

The process of coordinated dialogue includes recognizing the usefulness of data and/or key terms that can act as bridges to connect different disciplines and knowledges. Examples of this include a single case study or available data that can be analyzed from different perspectives. To identify those bridges, it is useful to work on collaborative schemes, flowcharts, or conceptual maps that capture existing information and identify 'nodes and connections' among the different disciplines.

Our experience at (CR)2 also shows that very often it is the investigators themselves who can act as a bridge between two or more disciplines, whether because of their research background, their role in the project, their education, and/or the support teams they have. This role can also be played by

post-doctoral researchers and Ph.D. students, who often have more time to dedicate to the project and can address objectives from an interdisciplinary perspective while gathering information exclusively for the project.

This also can offset the absence or imbalance of human capital that very often hinders interdisciplinary work.

Identifying differences among disciplines

Addressing highly complex issues also requires identifying spaces where the theoretical-methodological tools of a given discipline are not sufficient for an in-depth analysis of a particular issue. For this reason, during the design stage, it is important to create opportunities for researchers to speak about their particular investigative process, emphasizing the methodologies used, the minimum infrastructure required (equipment, budgets, etc.), the stakeholder relationships involved, timeframes for gathering and analyzing data and other considerations.

This should be accompanied by explanations of the potential contributions that each discipline can make to the project's central objective.

Designing and implementing work meetings

When working in an interdisciplinary context, it is not enough to set a date and time for meetings. While it may sound trivial, setting out a plan for the objectives and dynamic of a meeting or workshop can make the difference between its success or failure.

The value of designing work meetings is also important for addressing other obstacles that hinder interdisciplinary work such as the *time* that the researchers have available.

Clear, explicit description of objectives and roles

When a meeting is held in the context of an interdisciplinary project or investigation, it is crucial to have clarity about the objectives of the meeting itself. These should be made known to all participants, be adequately outlined in the meeting invitation and presented again at the beginning of the meeting or workshop.

Because of the multiple disciplines represented and the many responsibilities most researchers have (in addition to their participation in one particular project), it is commonly a challenge to keep the focus on the objectives of the meeting. Thus, it is important not only to explain these objectives, but also to reaffirm those of the investigation itself, thus enabling the participants to focus on the context of the investigation, and quickly situate them in the space for discussion.

In line with the above, one practice that contributes to the effective implementation of these kinds of co-constructed instances is to be clear about the roles and tasks expected of all those who facilitate the meeting or workshop. This can be achieved by creating a *script* that, among other things, sets out the roles, timeframes (the program), and interventions that are required.

Acknowledging the disciplines involved

In line with the point above, it is important when presenting or communicating aspects of a project, to mention the different disciplines and individuals involved. This is a rather simple way of reducing other gaps that hinder dialogue among disciplines, namely: the lack of shared knowledge among peers, which at (CR)2 may occur simply because of the large number of investigators and the diverse range of disciplines present at the Center.

Furthermore, practices such as these can also help to strengthen the sense of belonging of all those involved in the investigation or project.

Explaining key disciplinary concepts

Presenting knowledge generated in different investigations provides a unique opportunity for understanding the diverse languages present. The use of 'jargon' creates a language barrier that may

greatly hinder understanding and participation at interdisciplinary gatherings.

It is common for researchers to assume that all those present share the same conceptual and theoretical knowledge. And when a participant does not understand what is being presented, they become distracted and less willing to contribute to the discussion.

Still, more important than eliminating the use of jargon is to encourage the explanation of disciplinary concepts that are far removed from the other disciplines present; and this is also linked to the necessary exercise of problematizing our own field. In other words, the challenge consists in knowing how to clearly convey a message to all meeting participants.

Use of clear, well-summarized support material

To achieve what we have set out in the above points, it is crucial to use clear, well-summarized material. The form and content of the information that is provided and discussed at interdisciplinary gatherings should be considered carefully, with a view to facilitating understanding and providing opportunities for effective interdisciplinary reflection.

Our experience at (CR)2, particularly in larger meetings and internal workshops, has shown us the importance of organizing these spaces to make the work as accessible and effective as possible. Some practices and tools that can be used to enable this include:

- Providing the material to be presented in an attractive format prior to the meeting (videos, presentations, infographics) to reduce the time required for presentations and leave more time for discussion.
- In addition to tools that enable in-person work (flip charts, whiteboards), it is increasingly common for researchers to use digital platforms (Google Drive, Google Forms), software programs (MIRO, MURAL) and work formats (worksheets, work packages, mental maps) that enable *co-construction* both before and during the meeting or workshop.
- Building presentations with a section that clearly presents the structure and objectives of the workshop or meeting. Additionally, we recommend including in presentations, brief explanations of the concepts used, illustrative examples, or videos, to facilitate the effective, dynamic flow of information at the meeting.

Additionally, an effective visual or other kind of aid will help avoid questions about the project that range beyond the objectives of the particular meeting or workshop.

Foster dynamics that encourage participation

Our experience at (CR)2 shows that providing space for brainstorming, role playing, small group discussion, 2-minute scientific poster presentations and building collective conceptual maps, among other dynamic activities, lead to greater participation and increase the attention span of the participants, especially at long gatherings. These techniques foster more dynamic spaces of co-construction and provide a dynamic view of the complexity.

These formats also invite personal reflection and a sharing of the themes and concepts addressed, creating a space for effective learning.

Fostering opportunities for informal sharing and recreation

Lastly, it is important that during or after work, spaces for recreation be provided. At the Center, we have observed that such spaces provide a great potential for forging new connections among participants, as the language used becomes more flexible, the speed at which ideas develop increases and trust emerges more easily.

It is important to create opportunities for meeting that encourage dialogue among researchers who are part of the organization or research project. These

spaces foster discussion, the exchange of ideas and scientific dissemination, and build trust that enables real openness to other disciplines.

How can we evaluate the progress of interdisciplinary work?

> "We have a wealth and diversity of interpretations. There are processes that can be interdisciplinary, not just products." ((CR)2 investigator, Full Plenary Meeting, March 2019)

The practice of interdisciplinary work is intersected by multiple factors (methodological, regarding knowledge integration, linguistic, cooperative spirit, and others) that are not simple to see at first glance. As Mansilla et al. (2009) affirm, the development of interdisciplinarity has been accompanied by profound uncertainty regarding how to measure its success, or even how to define the success of a particular interdisciplinary study. As this handbook shows, interdisciplinarity is constructed through a process of critical, reflexive learning, and thus evaluating or measuring its progress will be closely linked to monitoring the process and the capacity for implementing the improvements identified in its ongoing evaluation (Lynch et al., 2015).

Both the literature and our experience at (CR)2 reveal three possible and complementary ways to measure progress in interdisciplinary work: document interdisciplinarity, encourage feedback and construct indicators.

Document interdisciplinarity

Observing and recording the investigative process and work meetings should be ongoing and are critical for evaluating progress in interdisciplinary work. In this regard, the idea of *process* is important in the sense that advancing in Interdisciplinarity goes hand in hand with lessons that are learned in the everyday effort to 'do interdisciplinary work'.

Documenting interdisciplinary work implies, first of all, making a record of the different kinds of gatherings carried out in the framework of that interdisciplinary work: work meetings, coordination meetings, workshops, plenary meetings, etc. To accomplish this, it is important to build capacities for recordkeeping, facilitating and monitoring the interdisciplinary process. This can take the form of minutes, notes, record sheets and even videos, that focus especially on the discussion and show, among other things, who says what (or at least which discipline they are working from), the issues addressed, how the discussion evolves and how agreements are reached (for each issue). Now, documenting these kinds of observations may not be entirely easy, especially because of the time required to do it. This is why it is important—whether in the context of an interdisciplinary project, or in the work of an organization or entity whose mission requires an interdisciplinary perspective—that there be a person or area dedicated exclusively to following up and evaluating interdisciplinarity.

Second, documenting Interdisciplinarity is related to the need to document the stages and phases of the investigation as it unfolds. It is therefore important (even essential) to use online collaborative tools: (Google Drive, Slack, Asana, Notion, among others). In addition to fostering the progress of collaborative work, in the sense that it enables all of the participants to be aware of the investigative process (according to the time they have available), and allowing researchers to overcome the 'face to face' barrier, keeping these kinds of records makes it possible to conduct an ongoing evaluation of the course and progress of the investigation, as well as to shed light upon different views that emerge during dialogues, thus making it easier to observe the investigative process in a critical, reflexive manner, accommodating reformulations and modifications as necessary.

Seeking feedback

Feedback, understood as an interactive process in which a response is received to the information initially transmitted, is crucial for measuring the

progress of interdisciplinary work, in the sense that it enables work methodologies to be adjusted and the needs of research teams to be anticipated. It is also a useful tool for improving the group dynamic, as it can strengthen ties among team members and build trust, commitment and effective communication (Lynch et al., 2015).

Both the literature and our experience at (CR)2 shows that feedback in the context of interdisciplinary work can be achieved, first and foremost, through *evaluation surveys*. These can focus on the interdisciplinary process in general and may be used at the end of each stage of the investigative process, or be handed out after specific gatherings (workshops, plenary meetings) to assess their effectiveness in fulfilling the overall and interdisciplinary objectives. Surveys should be designed to evaluate participants' (or members of the work team) views on the work dynamic, collaboration across disciplinary lines, products and expected results, composition and diversity of the group (taking into account variables such as gender, disciplines, geographic zones, among others), fulfillment of interdisciplinary objectives, leadership, working conditions, to name just some relevant aspects.

Second, feedback can take place during work retreats held exclusively to evaluate how the interdisciplinary work is going, and addressing similar issues as the surveys.

Lastly, feedback can be obtained from *ad hoc panels*, either internal or external. The evaluations and contributions obtained from external assessments can foster interdisciplinary work, when the external experts can offer perspectives that shed light upon blind spots inherent to the dialogue among the different scientific logics at play.

Since (CR)2's founding, the Center has maintained national and international panels of scientists and other professionals who observe and guide its scientific work and collaboration. One notable feature of the integrative themes, TISHi and TI-FAN, was the creation of advisory panels consisting of researchers from (CR)2's different lines of investigation. These panels discuss and evaluate the direction and progress of the research undertaken within each thematic area. In both cases, while these panels were not formed to evaluate interdisciplinarity exclusively, their feedback has been crucial for making improvements in this area.

Interdisciplinarity indicators

A final major line of action to assess the progress of interdisciplinary work is the construction of internal indicators that, on the one hand, measure how well each initiative is fulfilling its own and the Center's strategic interdisciplinary objectives, and, on the other, follow up on the degree of interaction across disciplines—in other words, monitoring the practice of interdisciplinarity itself.

Based on (CR)2's experience and the literature consulted, two groups of indicators have been identified—performance and monitoring—, that can be implemented in the organization as a whole, and within each interdisciplinary project or investigation. For each indicator, there must be a baseline, a goal and follow up frequency.

Final reflections

This manual is intended as a useful instrument for facilitating interdisciplinary work, first of all by providing conceptual resources that set interdisciplinarity apart from other collaborative approaches; second, by offering individual and collective principles that highlight the need to foster epistemic, theoretical and methodological openness to conveying and integrating disciplinary knowledge in a way that serves understanding and the search for interconnected solutions to complex problems; and, third, to provide concrete methodological tools for conducting interdisciplinary projects and investigations.

A further objective is to convey (CR)2's experience with interdisciplinarity, or more precisely, interdisciplinarity as it is practiced at the Center: the orga-

Indicator	Applicability	
Performance indicators	**Organizational level**	**Project/ investigation level**
Number of investigators and/or professionals from social science and natural science disciplines in the organization or project	✓	✓
Number of scientific contributions (scientific articles or products) with two or more authors from different disciplines	✓	✓
Number of meetings (plenary meetings, workshops, seminars, etc.) with participants from the different disciplines represented in the organization or project	✓	✓
Number of scientific projects or investigations with investigators or professionals from different disciplines	✓	
Number of theses co-supervised by investigators from different disciplines	✓	✓
Number of theses with an interdisciplinary research object or problem	✓	✓
Monitoring indicators	**Organizational level**	**Project/ investigation level**
Monitor the composition and representation of different disciplines in the organization or project	✓	✓
Monitor and keep records of interdisciplinary meetings and/or workshops	✓	✓
Monitor the methodology for implementing interdisciplinary projects and investigations	✓	
Monitoring integration among disciplines (in conceptual and methodological terms and in relation to knowledge) within interdisciplinary projects and investigations	✓	✓

nizational, methodological, and scientific progress we have made in this sphere. More than a result or goal to be achieved, (CR)2's case demonstrates that interdisciplinarity should be understood as a critical, reflexive learning process.

Interdisciplinarity does not construct itself. It is the result of collective, coordinated, participatory work among actors from different fields or disciplinary realms. Interdisciplinarity is complex, multi-leveled and multi-faceted (involving disciplines, methodologies, and knowledge produced). Interdisciplinary practice requires dialogue, communication and participation, as well as a rigorous design to ensure that each stage is enriched not only by data, information and evidence from the different disciplines involved, but also by the reflection that is generated in the co-construction of the investigation process and by the building of work partnerships and relations built upon trust.

As the previous pages show, doing science, above all interdisciplinary science, is also a construct influenced by motives, intuition, curiosity, agreements and disagreements. For most of the investigators at (CR)2, 'doing interdisciplinary work' is a learning experience that, as with all scientific methods, results from a process of trial and error. This manual is part of that process. Today, we are at an intermediate stage in our interdisciplinary learning process, a stage in which we can point to major advances, yet recognize the challenges still to be faced if we are to

affirm that we are "doing science" in a truly interdisciplinary way, in the sense of achieving conceptual, methodological and epistemological integration.

Our experience at (CR)2 has led to several important lessons learned that should be considered to strengthen interdisciplinarity, several of which we have listed below as recommendations. Thus, to strengthen interdisciplinarity both at the organizational level and in the design and implementation of projects and investigations, it is crucial:

- To ensure the design stage of a project is participatory, with contributions from different disciplines incorporated both into the definition of the research question and objectives, and in defining the stages of the work.
- To form interdisciplinary work teams that work strategically and collectively during all stages of the investigation.
- To design methodologies for co-constructing the work that ensure a collaborative intermediate stage, the construction of shared conceptual frameworks and recognition of both common ground and differences among disciplines.
- To identify information and analyses that can serve as bridges across disciplines.
- To work on creating mechanisms that prevent multitasking during meetings, workshops and other important instances for reflection and information exchange, and instill habits that encourage active listening.
- To work individually and collectively on communicating evidence in a clear and concise manner.
- To promote encounters that encourage dialogue among different disciplines, to foster discussion, the exchange of ideas, communication and genuine openness to unfamiliar disciplinary contexts.
- To build capacities for recordkeeping, facilitating and monitoring of the interdisciplinary process.

Lastly, we hope that this manual will be a useful tool not only for (CR)2, and particularly for the integrative themes we are currently pursuing, but also for other research centers, especially FONDAP, whose research hubs make the pursuit of interdisciplinary questions and approaches imperative.

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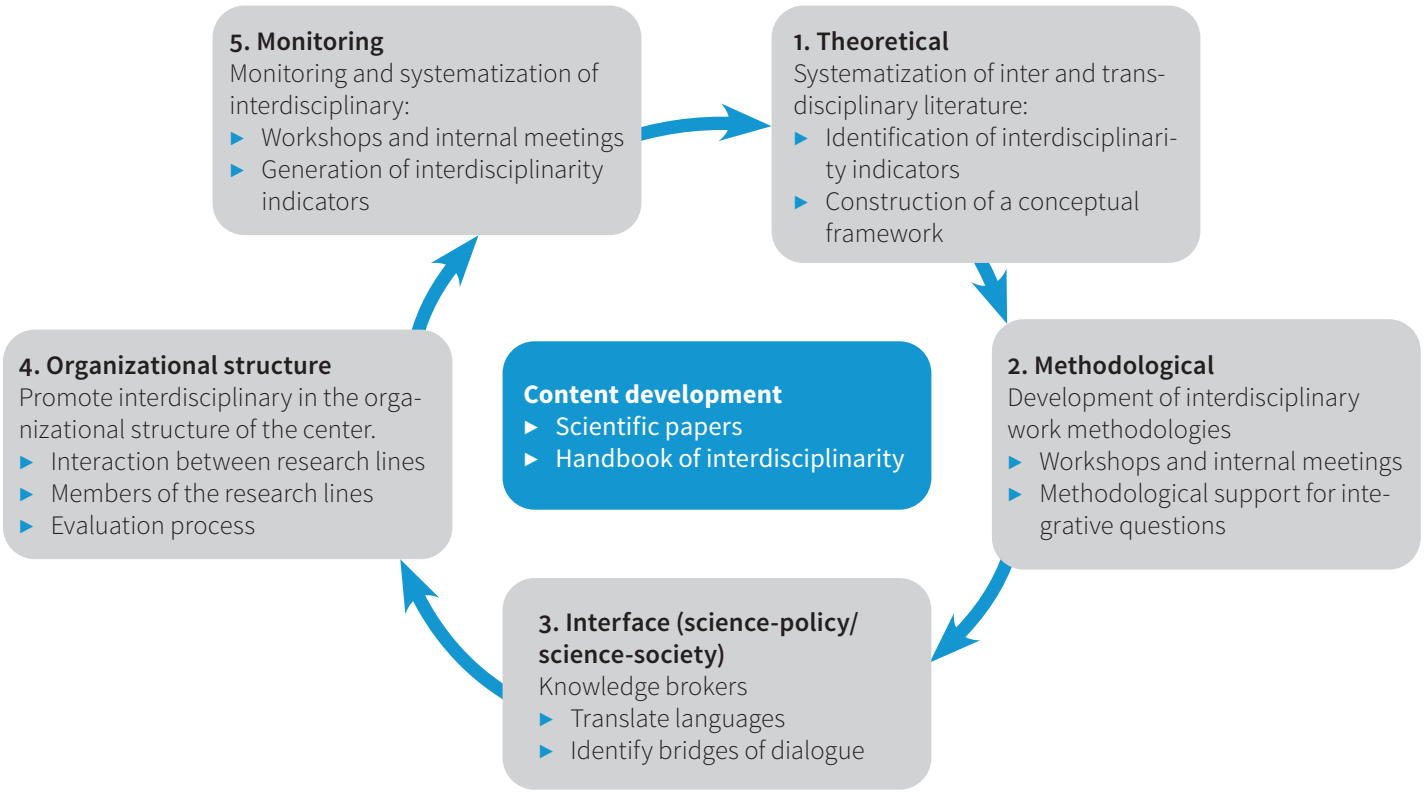
Annex 1: Dialogue and interdisciplinarity areas of work at (CR)2



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