INTERDISCIPLINARY ORIENTATION

Learning to navigate beyond your discipline

Universiteit Utrecht

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Learning to navigate beyond your discipline

Colofon

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CONTENTS

INTRODUCTION

Positioning this booklet

Interdisciplinarity is an increasingly popular term, especially in higher education, and it will most likely accompany you all throughout your studies and into your working life. For those who are not familiar with interdisciplinarity, we will explain the term in more detail later on. To put it simply for now, in interdisciplinary studies two or more sources of knowledge (i.e. disciplines) are integrated to answer a complex question more holistically.

Why has "interdisciplinarity" become such a buzz-word, and why now? The short answer is: the world needs it. The 21st century comes with problems of unprecedented scope and complexity that can be matched only with the according innovation and a wide-angle or bird's-eye view. It is essential to try and grasp the bigger picture because when working on complex problems, especially on a global scope, a large variety of interrelated factors matter for understanding and solving problems. That is also why many 21st century problems have achieved the flattering title of "wicked problems" (Rittel, 1973), which is your key term in case you want to dig into the related literature.

With such levels of challenge, risk and - in many cases - urgency, more and more people have come to acknowledge that disciplinary efforts in isolation cannot live up to the task, nor to the required knowledge and skillset. Hence, we need to facilitate interdisciplinary teamwork, and this is what the little booklet you are holding tries to do: facilitate your development in an interdisciplinary direction by raising awareness of the additional challenges and required competencies when working in a multi- or interdisciplinary team. Often these individuals are indicated as "capital T", a new generation of scientists with both rigorous disciplinary training and therefore being rooted in a discipline (represented by the vertical line) and the ability to think on a broad, connective level and thus to fruitfully collaborate with experts from other disciplines (represented by the vertical line).

Interdisciplinary work is valuable for many reasons. Many interesting scientific questions can be found at the interfaces between disciplines. For example, the computational and statistical power of mathematics and the research facilities of the physical sciences are required for making sense of, for example, genomics, proteomics, epidemiology, structural biology, and ecology. Interdisciplinary curiosity can lead to major breakthroughs, when researchers are aware of developments outside their own domains. For example, it was Charles Darwin's reading of Malthus's "An Essay on the Principle of Population" that led to his theory of natural selection. Similarly, many research triumphs are products of interdisciplinary collaboration, such as the discovery of the structure of DNA, magnetic resonance imaging, human genome sequencing, the "green revolution," and manned space flight (Institute of Medicine, 2005). Finally, wicked problems of global importance, such as disease prevention and global climate change, can best be addressed through interdisciplinary collaboration. In short, chances are high that you will be collaborating with scientists from other disciplines in your future job. Therefore, in your bachelor programme and with this booklet we intend to prepare you for this interdisciplinary collaboration, to turn you into a scientist who is capable of working in a world confronted with wicked problems.

Valid concerns and how we respond

In writing this booklet and promoting interdisciplinary work, we acknowledge the voices that raise concerns about a loss of quality in the transition from disciplinary to interdisciplinary work. Specifically, critics fear that disciplinary expertise will stagnate or even deteriorate and give way to superficial, sweeping ideas generated by enthusiastic interdisciplinarians, who are 'experts on nothing'. These are valid concerns and our response is the following. We support both disciplinary and interdisciplinary expertise, and in particular we believe that they best go hand in hand. This motivates our emphasis on collaboration. Interdisciplinary teamwork allows researchers to uphold the quality standards of disciplinary expertise while still creating interdisciplinary insights: what it needs to succeed are complementary team efforts. These build on a certain skill set or "toolkit", which we introduce in part II of this booklet. Figure 1 illustrates how we imagine the pathways of expertise as developed in bachelor and master programs can coexist. Our vision is that scientists with interdisciplinary competencies in their academic skills toolkit, trained from their undergraduate studies onwards, could effectively work in interdisciplinary teams, where the best of both broad and deep disciplinary thinking is united.

Our vision is that interdisciplinary teamwork would bring together the best from both the deep and the broad-level thinking if disciplinary experts develop additional, interdisciplinary competencies in their academic skills toolkit from their undergraduate studies onwards. We believe that the basic competencies and attitudes we discuss in the following pages need time and practice to allow you to grow into the challenges of working in multidisciplinary teams. We now turn to the composition of an interdisciplinary team, and how we believe the disciplinary and interdisciplinary forms of expertise can enhance each other.
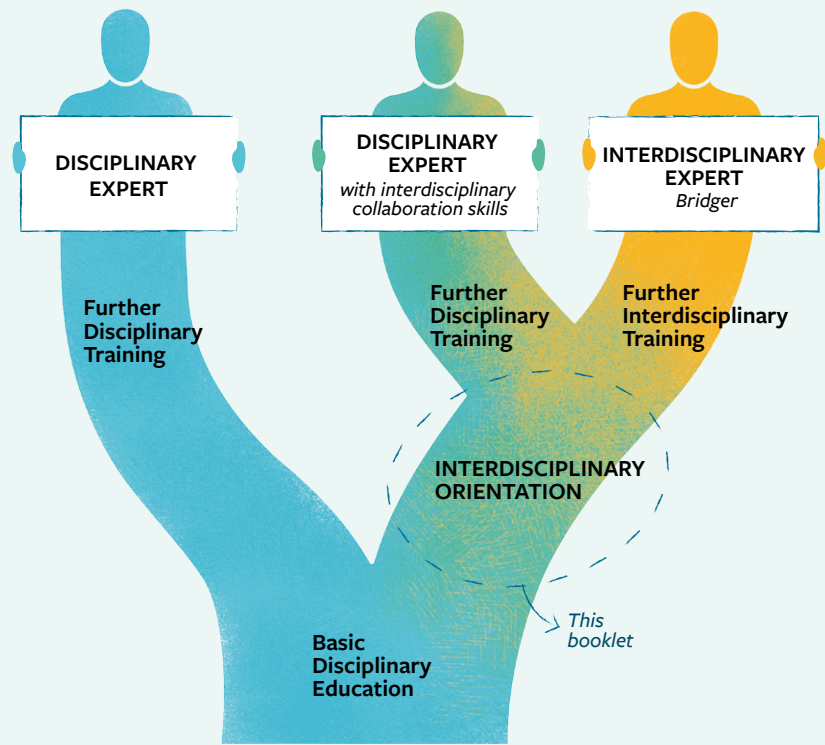
Figure 1

Pathways of development and positioning of this booklet. The different pathways represent the formative process during Bachelor, Master and/or PhD programs, as well as internships and other work experience. Note that the ends of the pathway are symbolic positions; in reality, we believe that you continue to develop expertise throughout your entire life. The circle in the right branch indicating "Interdisciplinary Orientation" is where we position this booklet, aiming to supplement your academic toolbox with an awareness of the basics that are needed to work in interdisciplinary projects in the future.
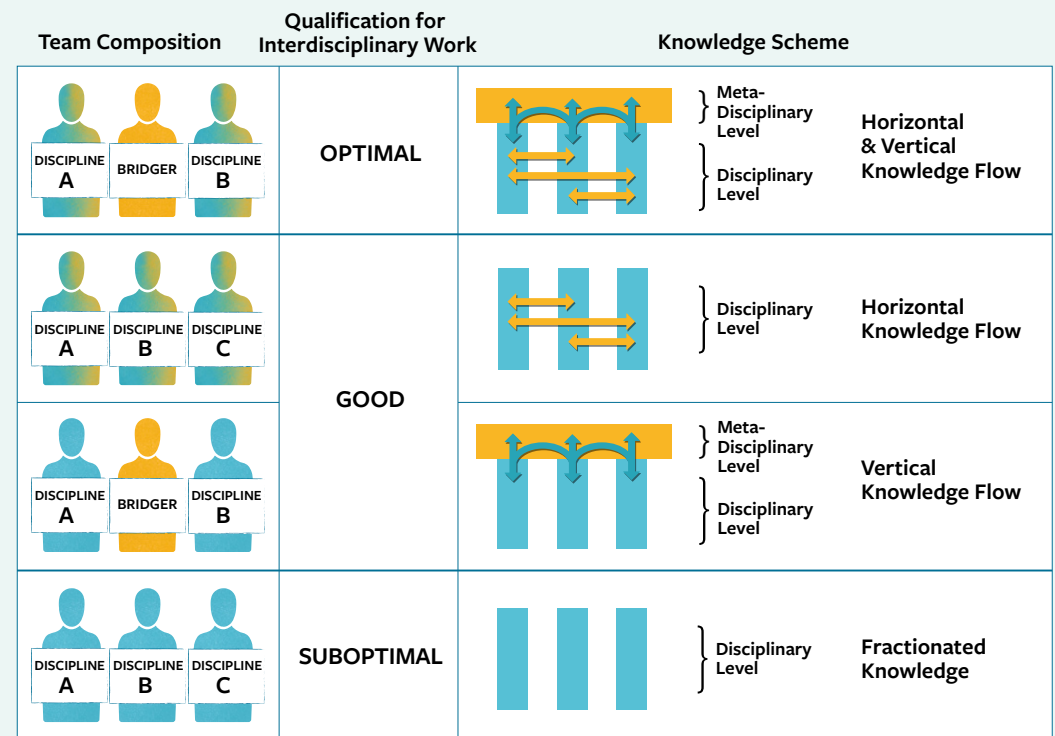
Figure 2

Team composition, functioning of different positions and the associated communication/information flows between members of multidisciplinary teams working on interdisciplinary problems.

Team composition for interdisciplinary work

According to this collaboration-based model, an optimal interdisciplinary team would comprise both disciplinary and interdisciplinary experts, as in the first row of Figure 2. More precisely, each discipline involved in the project should be represented by at least one disciplinary expert with an interdisciplinary orientation, and to further facilitate teamwork quality, an interdisciplinary expert should oversee and guide the process. Below is an illustration of such a composition. In the knowledge scheme of Figure 2, the orange bridge and several blue stems represent the complementary elements of breadth and depth in the interdisciplinary approach: each of the stems stands for the in-depth knowledge of one disciplinary expert, while the horizontal bar stands for the breadth of the interdisciplinary expert's horizon. The relationship between the two elements is reciprocal: disciplinary expertise provides the foundation and supports interdisciplinary expertise. Interdisciplinary expertise in turn provides overview and connection for

disciplinary expertise. This reciprocal relationship applies both to the level of task division, and to the epistemological level (see information box "Epistemology").

EPISTEMOLOGY

Epistemology comes from the Greek words "episteme" (knowledge / understanding / acquaintance) and "logos" (account / argument / reason) (Steup & Neta, 2020). Taken together, this makes epistemology the branch of philosophy that occupies itself with the study of knowledge. Epistemologists ask questions such as: What is knowledge? How do we gain knowledge and when are we able to say that we know things? Are there limits to what we can know?

In regard to task division, the team is composed of disciplinary experts who dig deep into the matter and are able to offer the necessary disciplinary expertise, and an interdisciplinary expert who helps in connecting the dots and building bridges, as well as "translating" between disciplines when necessary and facilitating dialogue. Epistemologically, the team is rooted in disciplinary groundwork and elevated by meta-disciplinary reflection.

Of course, the above description of the optimal interdisciplinary team is not the only well-functioning team composition for interdisciplinary work. Indeed, a good interdisciplinary team may also comprise several experts from different disciplines who have oriented themselves in an interdisciplinary direction and developed some of the necessary skills for interdisciplinary teamwork during their Bachelor and Master programs. In this scenario, the second row of figure 2, interdisciplinary work can be very stimulating and successful, as long as an open and fruitful conversation culture is maintained. However, there is a higher risk of friction or dead ends, since the team might miss the addition of someone who is experienced in taking a step back and engaging in meta-reflection on the involved disciplines and their underlying assumptions (read more about meta-cognition in the section on "systems thinking" in part II of the booklet).

Similarly, the team in the third row can do good interdisciplinary work, as it comprises several experts from different disciplines who provide the necessary depth and one interdisciplinary expert who provides the necessary breadth. However, this kind of team may also experience some tougher challenges: If the disciplinarians are unacquainted with interdisciplinary thought, this may result in communication difficulties or conflicts of opinion that are too much for an interdisciplinary expert to resolve.

What is the least recommendable, however, is a team composed only of experts from different disciplines with no interdisciplinary orientation, as represented in the fourth row. Although this team may still work in an interdisciplinary manner, the lack of experience in switching perspectives and communicating across fields may lead to frustration. The chances of arriving at an insightful and encompassing interdisciplinary product bigger than the sum of its parts are significantly lower. Nevertheless, gaining insight into different perspectives on a complex problem (without interdisciplinary integration) is already worthwhile and can positively change the way you approach teamwork in the future: with more nuance, openness and the ability to step out of your own shoes. This is a great quality not only in interdisciplinary, but also in disciplinary teamwork, since perspectives usually differ not only between disciplines, but also between individuals. You can therefore consider interdisciplinary training as mental gymnastics, where the process itself is beneficial even when you do not reach the goal you have set for yourself.

UP TO YOU – PICK IT APART!
Note that the illustration in Figure 2 is not supposed to be exhaustive, nor is it absolute. Its purpose is to give you a framework with which to analyse and reflect on your experiences and observations of team compositions in interdisciplinary work contexts. When you make experiences with interdisciplinary teamwork, we encourage you to re-consider our evaluation of the functionalities and quality of work in these different team compositions. If you meet someone who has such experience, you can also show them this page and ask for their perspectives.

A common mockery goes:

"Specialists know more and more about less and less until they know everything about nothing. Generalists know less and less about more and more until they know nothing about everything."

This statement, of course, is unfair. Domain experts are experts in a small subfield but often have a good awareness in a small area around that. Generalists, too, don't walk around proclaiming to know something about everything, but rather have more surface-level insights in a selection of disciplines or subdisciplines and focus on identifying connections and differences. With good communication, we can have them balance each other in interdisciplinary teamwork to get the best of both – The breadth of the generalist with the depth of the specialist!

Taken together, we hope to create awareness for different team compositions and thus ways of collaborating in interdisciplinary projects, some of which are more and some less conducive to successful and inspired interdisciplinary work. The constellations we have discussed and their evaluation is not final, nor comprehensive, but is rather meant as a starting point to spark your critical reflection on team dynamics and skill distributions. It might help you to observe in your own and others' experiences what kind of team is at play and how this affects the quality of the process and the product. You might come to disagree with our analysis, or expand the repertoire of team compositions for yourself and find new ways in which individuals may complement each other's forms of expertise.

Future paths after reading this booklet

This booklet helps you as a disciplinarian to develop an ***interdisciplinary orientation.*** You can understand 'orientation' not only in the sense of 'interest' or 'outlook', but also as the ability to 'find your way around' by starting to develop an expanded toolkit. This means that if you develop a sense of interdisciplinary orientation, you can navigate between disciplines, which involves a good deal of reflection on your own disciplinary background and how it relates to other disciplinary approaches.

As you can see in Figure 1, adopting an interdisciplinary orientation can prepare you for different future paths.

1. *Becoming an interdisciplinary expert (=bridger)*

If you like to **think broadly** and have a wide variety of interests, enjoy the bird's eye view on a (complex) topic, feel comfortable in the role of a translator and communicator between disciplines, a facilitator of experts, a networker who builds bridges – then you may want to look for an interdisciplinary masters education in a field that interests you, preferably one that enhances research, management, communication and networking skills. You also need to further delve into the literature on interdisciplinarity and team-work.

Note that you can't do it all. If you want to devote more of your time to said interdisciplinary skills, you will have to rely on disciplinary experts for scientific input and respect that they will criticize if you try to do without: it is safe to assume your understanding of the relevant fields does not reach deep enough. That is because as a full-blown interdisciplinary expert, your expertise lies not in any particular discipline or field of knowledge, but in facilitating collaboration between experts and in building bridges between knowledge from different fields. The expertise of an interdisciplinary specialist is essential in the composition of an optimal interdisciplinary team.

2. *Becoming a disciplinary expert with an interdisciplinary orientation*

If you like to **dig deeper**, if you are hooked on a discipline and want to specialize further to become an expert on a topic you love – then you should look for the corresponding disciplinary master in your chosen field that will make you feel like a fish in the water. Developing an interdisciplinary orientation is a less defined path, but can involve educating yourself by watching documentaries, attending talks or doing some light reading on a subject matter that is outside your discipline, in order to develop some awareness of important subject matters in other disciplines. To start reflecting on your own discipline on a meta-disciplinary level, you could look at the philosophy and research culture of your own discipline, reading authors who attempt to answer questions such as "why are we interested in this kind of inquiry?" and "why are we attempting to answer our questions in this particular manner?" Reading and reflecting on the shortcomings of your own discipline can also be a valuable exercise to open you up to critical perspectives. It is a life-long process to keep developing your expertise and a deeper understanding of your own discipline. However, once you have an advanced ability to step out of your own perspective and created a deepened awareness of where your discipline stands in relation to other disciplines, you can work on the interpersonal skills required to col-

laborate with experts from other disciplines. To do that, you might like to then look for projects to join that tackle problems from multiple disciplinary perspectives. By making experiences and learning from them, your depth of disciplinary knowledge combined with an interdisciplinary orientation can become extremely valuable in interdisciplinary teamwork.

Preview of this booklet

The purpose of this booklet is to
▶   introduce you to the meaning and function of interdisciplinary work
▶   help you become aware of your future options, skills and preferences
▶   appreciate the challenges of interdisciplinary teamwork
▶   provide you access to the essential literature in the field of interdisciplinary work

In particular, this booklet is structured in three parts, which aim to
I.   equip you with a basic theoretical understanding of interdisciplinarity and its implications,
II.   introduce you to the necessary skills and challenges of interdisciplinary work and
III. provide you with interdisciplinary exercises, examples of interdisciplinary work experiences by researchers and their tips for practical guidance.

Alongside this progression from theory to practice, you will find many tips and food for thought to help you reflect on your own intellectual perspective, the relationship between different disciplines and what is needed to integrate them into more holistic understanding and problem-solving approaches.
Feel free to scribble thoughts and notes on the margins – this is work in progress! Enjoy.

Why keep reading?

What's in it for you? That's a valid question to ask and we have three main answers.

CAREER PROSPECTS

The first is a pragmatic answer for the professionally ambitious reader: interdisciplinary interests and skills are indicators for intellectual success. Take for instance the finding from different surveys that graduates who chose an interdisciplinary approach to their dissertation research are significantly more likely to be employed within academia (Millar, 2013). This might have to do with the fact that collaborating across disciplines can enhance research visibility via a larger network of co-authors (Fortunato *et al.*, 2018)

and hence increase your chances of getting noticed. Another aspect is that often new insights, innovations and developments take place at the overlap between disciplines (National Research Council, 2010). Further, interdisciplinary teams tend to achieve higher rates of publication than monodisciplinary teams in the long term (Hall *et al.*, 2012). Although interdisciplinary papers may have less academic impact over short timescales, they generally have larger impacts in the long run (Van Noorden, 2015).

All these advantages could be interpreted in various ways. For instance, they could reflect an overall academic trend towards interdisciplinary research, driven by the necessity of dealing with complex global issues. Another interpretation could be that interdisciplinary research fosters skills that make you a more desirable employee in academia and beyond (this will become an increasingly plausible explanation as you read through part II of this booklet). Either way, you can rest assured that interdisciplinary orientation and training will give you an advantage in your professional development.

If you strive to make a bigger impact, you might like to hear that open-mindedness towards different disciplines is a highly represented trait amongst Nobel prize winners (Root-Bernstein *et al.*, 2008). Indeed, Nobel laureates are more likely to practice arts and seek input from many different fields to inspire their thinking (Root-Bernstein *et al.*, 2008). Let one of them, the innovative economist Kenneth Arrow, tell you: "subject yourself to new experiences whenever you can." This curious attitude has led him to systematically explore what is most unfamiliar to him, following his motto "it is so far from anything I do. I must be interested" (Scheffer *et al.*, 2017). This open-minded, out-of-the-box kind of thinking is precisely what you cultivate as an interdisciplinary thinker.

PERSONAL PROSPECTS

The emphasis on skills and attitudes leads us to the second, more idealistic answer for the personally ambitious reader: developing an interdisciplinary orientation spurs your personal development. It is highly challenging and fosters skills not only on the intellectual, but also on the social and personal level; and on all these levels, interdisciplinary skills can open doors for you that you may not even know exist! That is because interdisciplinarity by nature requires you to step outside your comfort zone and reflect on yourself and the world in new ways. It is, so to speak, an eye-opener – not only intellectually.

IDEOLOGICAL PROSPECTS

The third answer takes the idealistic approach a good bit further, speaking to those of you who value knowledge for its own sake. To you, it will be relevant to consider that interdisciplinary research sets particularly ambitious standards for reaching satisfactory answers to (complex) research questions. More concretely, the purpose of the interdisciplinary approach is to reach a better understanding of a topic or problem than any of the disciplines could do in isolation. The reasoning behind this is roughly that combining different disciplinary perspectives might bring us closer to the truth by giving a more complete and nuanced understanding of an issue. You can compare this to asking sever-

al witnesses what happened in an accident at the corner of the street yesterday at 3:05pm and then putting the pieces of information together in a narrative that unites multiple perspectives, hoping that way to get the best possible idea of what "really" happened. That approach intuitively seems more promising than consulting one witness alone. It must be noted here that aiming to get closer to the truth does not assume the possibility of reaching it. Though this issue can be disputed at length (just consider the extensive history of philosophy of science), a current wide-spread consensus amongst philosophers of science is that there is no such thing as an 'objective view on things' or an 'accurate representation of reality' in the realm of the humanly achievable (Frigg & Nguyen, 2020; see also info box on "What is "correct" perception" on p. 35. To accept this means to take a humble stance towards the explanatory power and reliability of your own (discipline's) view on the world. Being humble is key to interdisciplinary thinking, because it enables you to seriously open up to other disciplinary views in the first place.

Some passionate disciplinarians may nevertheless believe that their perspective is the most objective or accurate, but that is in itself certainly a subjective, most likely inaccurate, and maybe a little arrogant stance. To put this into perspective, let's consider that despite their efforts, all disciplines are inherently biased by their own assumptions and the nature of their own approaches (including the types of questions they ask!). Therefore, they will often have equally valuable, but contradicting things to say about particular matters. Researchers with an interdisciplinary orientation try to go beyond their perspective-bound views by combining them with others, resolving contradictions and joining complementary findings in a joint effort. The goal is to arrive at a bigger picture that is more than the sum of its parts.

DON'T WORRY

Finally, there is also something to be said for those of you who, despite all our efforts, don't feel like reading on: Don't worry if you decide not to get involved in interdisciplinary work - that's just fine! You are equally needed as a disciplinary expert. As you know if you have read the introduction, disciplinary expertise is prerequisite to any kind of meaningful interdisciplinary work.

But before you close this booklet and put it away, give this a thought: you are likely to encounter more and more interdisciplinary work in your future academic life, no matter the path you take. For instance, you may be asked to review interdisciplinary articles on topics where your expertise is relevant, or maybe some of your colleagues will engage in interdisciplinary research and talk to you about it. Either way, this booklet can give you a basic understanding of what interdisciplinary teamwork entails, and that gives you an edge over your disciplinary colleagues who lack such insight. Being familiar with the workings of interdisciplinary research makes you a more desirable expert, more approachable, and probably also more interesting to a wider group of colleagues. Wouldn't it be worth flipping through these pages to be able to enter that larger conversation more smoothly? To know how best to interact and communicate your own expertise when you are consulted by an interdisciplinary team?

Structure of this booklet

Throughout this booklet we will approach interdisciplinarity from three complementing angles, as mentioned above. Here is a more detailed description of what these three parts contain:

I.   **Interdisciplinary Theory** - Learn about some theory behind interdisciplinarity. Why is it necessary? What exactly is interdisciplinarity and what not? What are all those other terms that sound similar, such as 'multidisciplinarity' and 'transdisciplinarity', and what do they mean? How does the interdisciplinary method work? Where does interdisciplinarity come from? What are its benefits and challenges?

II. **Interdisciplinary You** – This is where you explore your own development towards and through interdisciplinary thinking. Next to some qualities that are useful to foster and bring to the table when working in an interdisciplinary team, there are also a number of skills and attitudes you will acquire throughout the process (Figure 3). We discuss how regular reflection upon your decisions supports you in taking charge of your intellectual and personal development, your preparation for the job-market and will help you boost your CV.

III. **Interdisciplinary Practice** – In this final part, we leave you with some information on interdisciplinary learning goals and provide you with exercises to work towards them. You will also find assessment rubrics there to familiarize yourself with how interdisciplinary competencies are evaluated by educators. Next to this, you will receive some take-home tips and wisdom that can come in handy in your encounters with interdisciplinary work during and beyond your studies. You will get a glimpse at valuable experiences from interdisciplinary researchers and receive tips to help you complete interdisciplinary assignments. Finally, here is also where you get some headspace to check in with your own sense of interdisciplinary orientation and where you want to take it from there.

DISCIPLINARY EXPERT
with interdisciplinary collaboration skills

Individual characteristics

- Curious
- Collaborative
- Communicative
- Creative
- Critical
- Flexible
- Confident in your own disciplinary competencies
- Committed
- Empathic

In addition, each team player adds to the group qualities mentioned that characterize successful multi-disciplinay teams.

Group characteristics

Successful multidisciplinary groups are characterized by:

- Strong shared purpose
- Equitable distribution of tasks
- Fair & inclusive decision making
- Work in small subteams
- Responding to helpful & unhelpful behaviour within the team
- Fast & fair conflict resolution
- Authority to self-govern
- Collaborative & open relation with other groups

Figure 3
Disciplinary expert with interdisciplinary orientation. The indicated individual and group competencies will be explained in Part II and III of this booklet.

PART I
INTERDISCIPLINARY THEORY

What is interdisciplinarity and in what way is it different from multi-, cross- or trans-disciplinarity? These are valid questions which cannot be answered easily, but in this section we'll give it our best shot. You will learn more about what "interdisciplinarity" means, where it comes from historically, and how it has become a keystone for numerous programs. To make the concept more concrete, we will also walk you through some of the methodology that is useful in the interdisciplinary research process.
*In short, this section is meant to provide you with an overview of interdisciplinarity **in theory**!*

PART I
INTERDISCIPLINARY
THEORY

What is interdisciplinarity (and what is not)?

The definition problem

When you ask the Merriam-Webster dictionary, the definition of "interdisciplinarity" is vague at best: *"involving two or more academic, scientific, or artistic disciplines"* (n.d.). This definition is barely distinguishable from that of multidisciplinarity: *"combining or involving more than one discipline or field of study"* (Merriam-Webster, n.d.). What trumps this, however, is the definition of transdisciplinarity. Here, the dictionary does not even try to distinguish this concept but refers you directly to interdisciplinarity. Do those concepts really all boil down roughly to the same thing, as the dictionary definitions imply? The situation is rather confusing. To be fair, how can we expect clarity in dictionaries if even the experts are still struggling to define interdisciplinarity? Scholars working within interdisciplinary education and research have been on the bumpy road of attempting to define the nature of this process for decades. The apparent vagueness and disagreement over "interdisciplinarity" have led some scholars to discard the term altogether, even when quite evidently engaging with the concept[1]. Now, you might be wondering: Why bother with the definition?

[1] For example, read the introduction to Creative Marginality – Innovation at the Intersection of Social Sciences: "This is not a book on 'interdisciplinary' research – we reject the very notion: instead of broad, catch-all 'interdisciplinary' research, we find it is more realistic to combine two narrow specialties" (Dogan, 2019). After reading the definition we render you in this booklet, you can make up your own mind on Dogan's rejection of the term.

Why it matters

To define interdisciplinarity is a valuable quest because we see a unified definition as the first step towards agreeing on the purpose and, ultimately, the most desirable form of interdisciplinary research and education. Such agreement and clarity would help all scholars engaged in interdisciplinary studies to advance in refining and promoting its teaching strategies and research methods. Our approach to tackling the definition problem has been to break it down into more manageable pieces and start with the question:

What is a discipline?

A discipline is defined by the questions it asks, the methods and concepts that are employed to think about these questions and phenomena, and the theories that are accepted by experts to provide a standard for determining the validity of answers. More formally, Tripp & Shortlidge (2019) adopt the definition by Newell & Green (1982), summarizing a discipline as "a particular branch of learning or body of knowledge that can be distinguished by several factors, including the questions it asks via its ontological lens, epistemology and methodology regarding how these ideas are used to contribute to a body of knowledge composed of concepts, theories and facts" (p.4). Gardner (2000) set up a similar definition: "the concepts and methods for thinking about specific types of questions and phenomena; concepts and methods that have been cumulatively accepted by disciplinary experts as providing standards for determining the validity of answers".

WHAT SETS DISCIPLINES APART?

What sets disciplines apart depends on which disciplines you compare, and the same is true for what disciplines have in common. Commonalities and differences can be found at different layers, from the most fundamental theoretical layer (e.g. assumptions about what there is and how we can know) to more practical or layers of application such as the kind of subject matter, the scope of perspective and the particular kinds of techniques or materials used for research.

For example, physics and chemistry share the fundamental layer, assuming that "that the world is governed by deterministic or probabilistic laws which are in principle knowable" (Newell & Green, 1982), and they use a similar method. While they also often investigate the same theoretical or empirical entities (e.g., the electron or liquid benzene), the kinds of questions they ask about them can differ. Generally, chemistry tends to focus more on the details of molecular interactions, while physics usually concerns itself with a broader range of phenomena. Hence, the researchers' view on a certain entity sharpens at different levels of magnitude depending on the angle of the discipline (find more on this in the section 'Levels of Magnitude' under 'Systems Thinking'). In comparison, economics and sociology may investigate the same subject matter (e.g. urban problems), asking the same questions (e.g. "What are the causes of unemployment?"), and using the same methodology to come to answers. However, their fundamental assumptions and interests can differ considerably, as Newell & Green eloquently summarize: "Economics is all about how people make choices. Sociology is all about why they don't have choices to make" (Newell & Green, 1982). Analysing at what layer two disciplines differ is an important part of the meta-disciplinary view and prerequisite for having good interdisciplinary conversations. When disciplines differ in their assumptions on what there is and how we can know, that usually makes

communication the hardest. For instance, if a sociologist and an economist get deep into discussion without noticing that they are holding fundamentally different assumptions about societal structures, they are unlikely to learn much until they move their conversation onto that deeper level and start to understand each others' perspectives.

Take-Home Message: In interdisciplinary matters - whether you are the reader or the researcher - it is always helpful to realize not only on what layer(s), but also to what degree the involved disciplines differ in their approaches. This has a great impact on how easily they can be integrated.

What is interdisciplinarity?

The prefix "inter" means "between, among, amidst" or "derived from two or more" (Repko *et al.*, 2020). Its meaning in conjunction with the concept of "discipline" is explained in the following definition of interdisciplinary science by Tripp & Shortlidge (2019): "interdisciplinary science is the collaborative process of integrating knowledge/expertise from trained individuals of two or more disciplines – leveraging various perspectives, approaches and research methods/methodologies – to provide advancement beyond the scope of one discipline's ability" (p. 5). We will return to the definition of interdisciplinarity in more detail after providing an overview of terms that have to do with, or are often confused with, interdisciplinarity.

Teamwork

Notice the role of collaboration here; as part of the definition it is not optional, but essential to interdisciplinary science. This view may be challenged, but there is a lot to be said in its favor. For now, let us just consider that interdisciplinary work aims to build on disciplinary foundations; it cannot replace them. This means that interdisciplinary work is only ever as good as its disciplinary foundations.

INTERDISCIPLINARY TEAMWORK RESULTS FROM MULTIDISCIPLINARY COLLABORATION

"Interdisciplinarity" describes a process of integration of different perspectives, knowledge and insights. This means that individuals from multiple disciplines collaborate in interdisciplinary teamwork. Here, "collaboration" refers specifically to the *interaction* between individuals, while the term "teamwork" also encompasses the *work* they do together. Hence, we can say that the collaboration between multiple disciplinary scholars (= multidisciplinary collaboration) can result in the integration of disciplinary perspectives, knowledge and insights and may provide an interdisciplinary answer or solution (= interdisciplinary teamwork). Interdisciplinary teamwork can therefore be seen as a process and product arising from multidisciplinary collaboration.

Hence, many scholars who think about interdisciplinary education agree that in order to be able to do high quality interdisciplinary work, one first needs to develop the skills to navigate the disciplinary literature and to understand and interpret it according to the state of the art. For any interdisciplinary article, imagine a set of reviewers that are experts from the disciplines in use: these experts should be convinced. Given such demanding quality standards, in the limited time most people spend studying, it is unlikely for any single individual to become proficient enough in all disciplines relevant to a given interdisciplinary research topic. For this reason, and in favor of many other advantages gained in teamwork (see Part II, section "set your mind" and "personal development"), collaboration between team members trained in different disciplines is widely regarded as a prerequisite to interdisciplinary work.
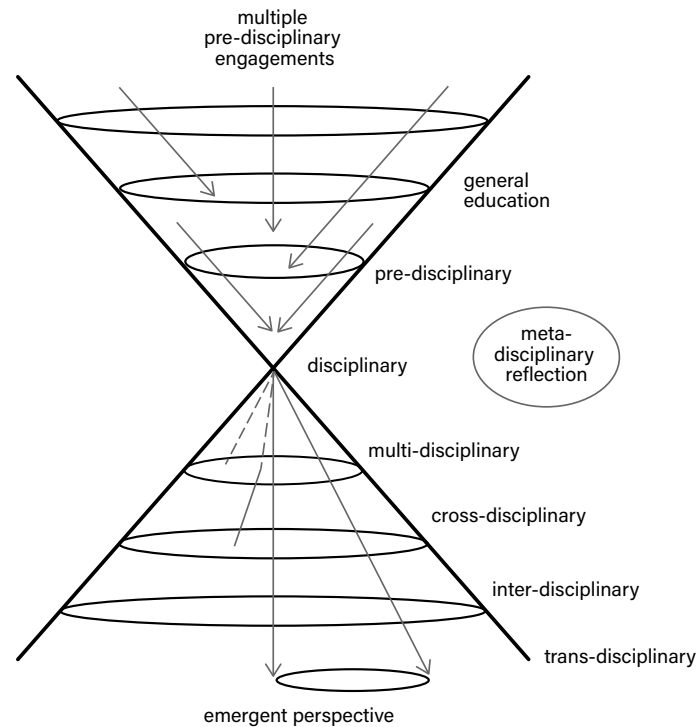
The funnel of expertise

Now that we have clarified the relationship between disciplinary and interdisciplinary work, let's look at some other related concepts. When insights or perspectives from different disciplines are taken into account, a number of approaches can be taken. You may have already come across a variety of words of the form *prefix + disciplinarity* during your studies, most of which you will probably recognize in the figure of the 'funnel of expertise' below. Below, we will define cross-, multi-, inter- and trans-disciplinarity, which are terms that are often confused or used as interchangeable with interdisciplinarity. However, they denote processes that relate to interdisciplinarity, but also differ from it, as we shall explain.

The 'funnel of expertise', which we borrow from Stein (2007), aims to provide an overview on the different forms of research and illustrate the differences and relationships between the concepts. The terms we will discuss are located in the lower part of the funnel, since they all involve some form of connecting different disciplines. Starting from the disciplinary focus point downwards, the rings represent successive stages of broadening horizons, increasing integration of disciplines, and deepening levels of expertise (Stein, 2007). Each stage requires certain additional skills on top of the previous ones, as each advanced form of research builds on the skills acquired in all previous forms.

Let's tackle them one by one.

Multidisciplinarity

… is the collecting of different disciplinary insights. This means that each disciplinary view is represented and standing next to the others with a validity in its own right. This is usually the result when scholars explore a topic from different disciplinary perspectives to get a fuller understanding of its various elements and the complexity of the topic. Such a multidisciplinary view is often a necessary step towards solving complex problems and it requires expertise in two or more disciplines. Both are true for interdisciplinarity as well, but multidisciplinarity is different in that it does not let the different perspectives and their knowledge and insights collide, fuse or cross-pollinate, and it does not seek to form a new, more encompassing explanation or understanding. One way to imagine multidisciplinarity is a curriculum in which the student gets to study several disciplines simultaneously, but separately. Multidisciplinarity is often experienced as enriching, as it may provide additional insight into the different perspectives of a complex problem.

multiple
pre-disciplinary
engagements

general
education

pre-disciplinary

meta-
disciplinary
reflection

disciplinary

multi-disciplinary

cross-disciplinary

inter-disciplinary

trans-disciplinary

emergent perspective

This model is called the "funnel of expertise", in which students first acquire disciplinary knowledge and afterwards slowly start to branch out to a more multi-, cross-, inter- and finally trans-disciplinary perspective. During this process emergent perspectives can be obtained. Metadisciplinary reflection is singled out because it influences each level.

Cross-disciplinarity

... is sometimes understood to be "a general term used to refer to any activity that involves two or more disciplines" (Szostak, n.d.). This concept therefore can be used to encompass multidisciplinarity, interdisciplinarity and transdisciplinarity. However, as portrayed in the funnel of expertise, cross-disciplinarity can also be understood as a stage between multi- and interdisciplinarity. As such, it entails the colliding and cross-pollinating of different disciplinary insights that multidisciplinarity lacks, however, it does not involve integrating them into a coherent whole. Disciplinary views are gathered and analyzed in conjunction, often resulting in adaptations of one view to another, in enrichment or fusion of disciplines, but at least in comparisons. In cross-disciplinarity, concepts or methods from other disciplines are often borrowed to enrich one's own discipline. You can imagine this as a multi-disciplinary curriculum in which teachers organize student discussions across tracks and exchange information across disciplines, for instance in the form of guest lectures by experts from disciplines outside a given track. Here, students would encounter a cross-over of different approaches to the same topic within a course and be challenged to adopt elements of these different perspectives in their thinking.

Interdisciplinarity

...is the integration of insights from two or more disciplines into a bigger, coherent picture. Conflicts need to be resolved in such a way that new insights emerge from the integration. The fusion of disciplinary understanding should result in a whole that is more than the sum of its parts. Imagine the cross-disciplinary curriculum being reformed in such a way that the different tracks are dissolved and the program is taught in "themes", with fusions of different disciplinary insights involved in each theme (if this idea appeals to you, you can search for interdisciplinary masters that have organized their curriculum based on themes rather than disciplines, such as the research master in European studies in Maastricht, in case you want to have a look at such a program).

Transdisciplinarity

...is the transgression of academic borders altogether – not just those within academia but also those between academia and the non-academic realm (Khoo, 2019). Transdisciplinary collaboration therefore most lends itself to applied problem-solving projects, where the contributions from directly affected practitioners and stake-holders are key to understanding the problem itself, to formulating applicable theories and planning realistic solutions. Such projects aim for a fruitful exchange of knowledge between science and society: on the practical level, scientific knowledge and understanding benefit real-life solutions, while on the theoretical level, the practitioners' knowledge and experience benefit scientific understanding. (This kind of collaboration also goes under the term "Mode 2" research, in case you would like to read some more about it; see Gibbons & Nowotny, 2001).

BOUNDARY-CROSSING

A relevant concept to get familiar with in context with trans-disciplinarity is "Boundary crossing". This term refers to the act of crossing boundaries between one's own and others' practices and perspectives with the aim of making new connections, learning from the 'other' and co-creating new practices (Akkerman & Bakker, 2011). Boundaries are defined as tensions or challenges experienced when people from various practices (e.g., a disciplinary, cultural, organisational, generational, ...) interact. When these boundaries remain implicit and the 'other' perspective is ignored in favour of one's own perspective, interaction and collaboration are usually hampered. However, when boundaries are made explicit and the others' perspective is placed side by side or even integrated with one's own perspective, interaction and collaboration are facilitated (Akkerman, 2011). This often leads to the creation of new and transformative outcomes (ideas, products, solutions, practices, ...).

The take-home message is that the encounter with boundaries generally represents important learning opportunities. We invite you to look out for the tension or discomfort you might experience when you touch upon a boundary. These are challenging situations, but when you are aware of what is happening, you can keep an open attitude and may come to cherish constructive friction!

Subtleties in the definition of interdisciplinarity

We have now worked our way through the funnel of expertise and contrasted interdisciplinarity with other, similar terms, hopefully clearing up misunderstandings as to how they differ. It is worth noting that if you do a search in the literature, you will still find varying definitions of interdisciplinarity. This does not necessarily mean that scholars disagree; sometimes, they just focus on different aspects of the term. In this respect, interdisciplinarity can be differently embedded in:

▶ the context in which the term "interdisciplinarity" is used (in research; education; social sciences / humanities / natural and life sciences; etc.)

▶ the aim with which interdisciplinarity is practiced (research to achieve a broader and improved understanding, to solve complex problems, etc.)

▶ the process in which solutions are achieved, such as the necessity of teamwork that we have discussed before. In this respect, it is interesting to note that in the natural sciences, life sciences and also in the social sciences, collaboration between individuals from different disciplines is generally seen as a requirement to achieve interdisciplinary understanding or solutions. In the humanities, however, this is not always seen as a necessity. Here, individuals may achieve interdisciplinary understanding on their own, based on the integration of disciplinary perspectives (e.g. van der Lecq, 2012).

To illustrate the subtle differences between definitions, consider the examples below:

One of the most widely used definitions of *interdisciplinary understanding* is drafted by Boix Mansilla *et al.* (2000) as: "The capacity to integrate knowledge and modes of thinking in two or more disciplines or established areas of expertise to produce a cognitive advancement—such as explaining a phenomenon, solving a problem, or creating a product—in ways that would have been impossible or unlikely through single disciplinary means." (p.219) Here, the focus lies on interdisciplinary understanding as a competency which can be achieved by an individual. As such, it can be trained and assessed.

In comparison, in another influential piece of writing, Repko *et al.* (2020; p.63) define *interdisciplinary studies* as: "a cognitive process by which individuals or groups draw on disciplinary perspectives and integrate their insights and modes of thinking to advance their understanding of a complex problem with the goal of applying the understanding to a real-world problem". This definition regards the interdisciplinary process and emphasizes its goal (to improve understanding of real-world problems). Note that Repko *et al.* (2019) also indicate that both individuals and groups can achieve interdisciplinary solutions, which has been debated.

> **TAKE-HOME MESSAGE ON THE DEFINITION OF INTERDISCIPLINARITY**
> It is safe to say that all definitions emphasise the core of interdisciplinarity, namely *the integration of disciplinary perspectives and insights*. Furthermore, in the Sciences, *collaboration between scholars from different disciplines* is emphasised as a crucial element.

The illustration in Figure 4 gives an overview of the interdisciplinary process. We will walk you through it with a special focus on the different kinds of viewpoints needed along the path, as well as the qualities and attitudes, skills and tools most crucially involved. You can read more on these in Part II of the booklet.

1. First of all, the interdisciplinary process starts with disciplinary expertise. This is needed to dig deep into the various pools of knowledge and insights that are relevant to the research question or problem at hand. At this point, the interdisciplinary expert needs to take on a **curious** and especially **humble** attitude and be aware that the disciplinary experts are the ones upon whose work all else will depend. Hence, as an interdisciplinary expert, you do best to consider yourself an apprentice during this first phase. Ask a lot of questions and let yourself be taught. The more you learn from your teammates now, the better you can help them later! This requires you to be **flexible** as well, since you probably need to do quite some mental gymnastics to switch between the different ways of thinking amongst the disciplinary experts. As a disciplinary expert, this is your time to go all the way: Be **committed** to your task because the team depends on your particular expertise. You may not have the luxury of a second, equally well-informed opinion, hence you need to be thorough in representing your discipline's best contributions.

2. Second comes the sharing of insights and looking at them in conjunction. This can be considered the multidisciplinary part of the process.
As a disciplinary expert, presenting your findings to the team requires **confidence in your competence**, and sometimes also **courage**. For instance, you might notice that your perspective appears strange to colleagues from other disciplines or that there are prejudices held against some of your methods and approaches. This is not a personal issue, but a 'cultural' one; try to keep holding yourself up to your own disciplines' standards and to stand up for your good work. At the same time, use your **empathy** to remain aware that your colleagues are in the same position as you. Everyone involved may now be confronted with unfamiliar views. This can be uncomfortable, but that discomfort is a good sign. It means that there is potential for progress together!
As a disciplinary expert with interdisciplinary orientation, you can help out a lot at this point by **flexibly** stepping in and out of your disciplinary perspective to facilitate everyone's understanding. Here too, **empathy** is key, but also disciplinary **humility**, as you may need to be careful not to make absolute statements or assume a superior position. The interdisciplinary expert is the one most qualified to take the multidisciplinary viewpoint. This entails identifying what contributions have been made from the different disciplines and whether they have all been equally well explored, expressed and understood. You need to be **critical** when you find that part of the research may need further refinement - but be tactical in when and how you communicate this respectfully and constructively. In team meetings, it is probably best if

you chair the proceedings and moderate when necessary. You need to be especially **communicative** at this point to ensure that all perspectives are properly shared and that the different experts do not take each other's space, or, on the other extreme, neglect one another's contributions. An open and respectful atmosphere is crucial and you may have to do some translating work until all perspectives have come across.

3. The third phase is one of picking apart all disciplinary contributions and going back and forth between analysing their relations down to the detail (paying attention to differences as well as common ground) and bringing them together in different ways. This is a phase of trial and error which can be considered as playful, though in a systematic manner, since it is all about exploring and at the same time getting to know how different elements of a system may hang together. **Systems thinking** is therefore a crucial tool in this part of the process.

That kind of thinking entails expertise in taking a meta-disciplinary view, hence it is important that disciplinary experts recognize this as a time in which they need to be patient and support the interdisciplinary expert in developing a multidisciplinary analysis. Besides humility, this may often require disciplinary experts to be **flexible**, as their findings are likely to be used, reshaped and interpreted in new and possibly unsettling ways. Furthermore, it is inevitable that some disciplinary darlings will have to be killed, which can sometimes lead to frustration on the side of the disciplinarian who has invested time and effort into the corresponding research. To overcome this frustration and see the bigger picture requires **reflection** and a **collaborative** attitude. It may also help to consider that nothing is set in stone at this point, and for that reason it is also advisable to keep track and collect discarded information. Some of it may return to the table later in the process.
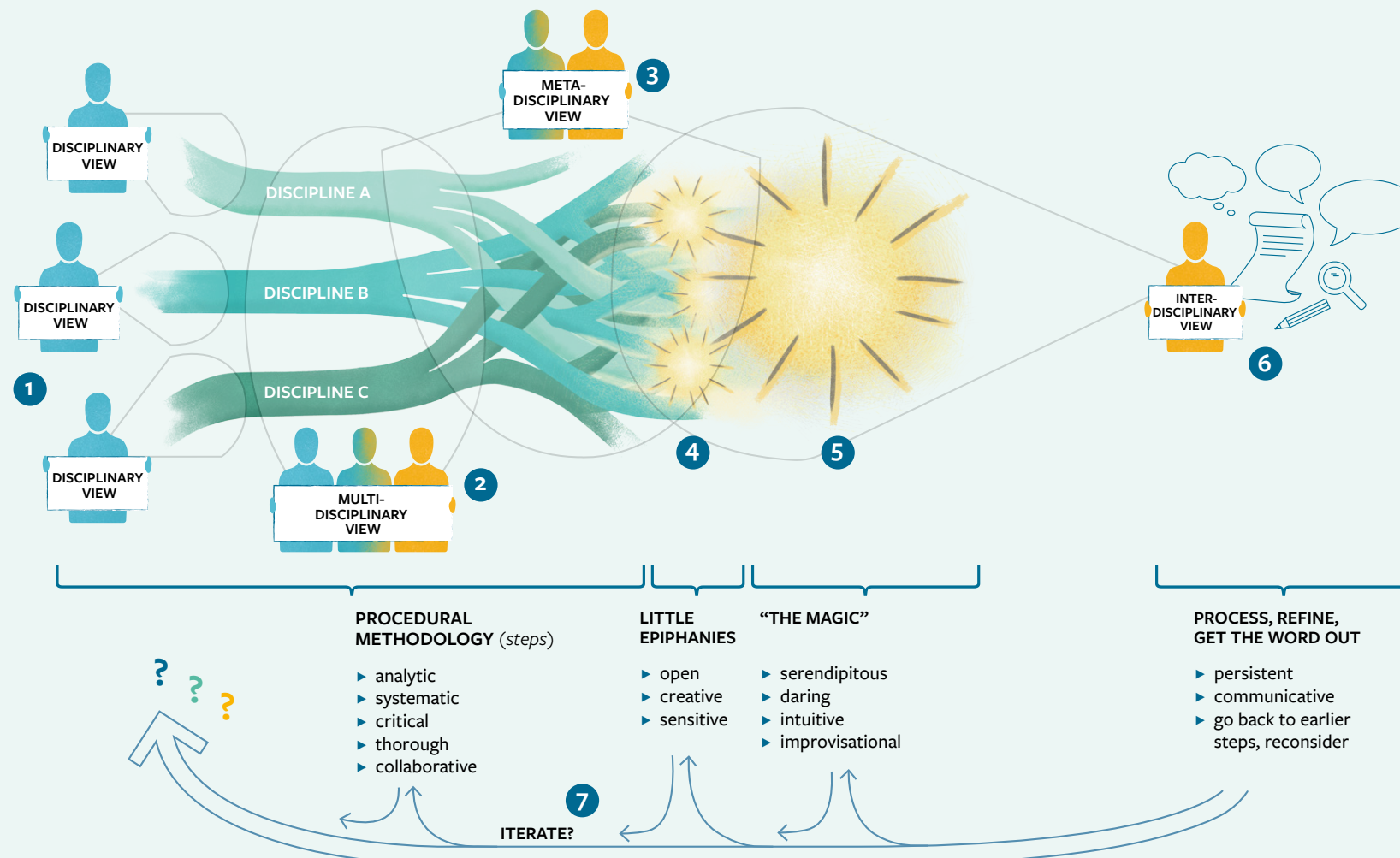
Figure 4
The interdisciplinary process consists of the different disciplinary perspectives (multi-disciplinary overview), an analysis and comparison of their findings, notions and concepts to find common ground (meta-disciplinary overview) as well as the emerging interdisciplinary insights followed by communication of the result. Note that the process as portrayed here is linear for the sake of conceptual clarity. In real life, it is usually iterative and a lot more dynamic. At any point in the process, what you learn may lead you back to earlier stages, where you may need to adapt or refine your work.

4. This stage of the process is where things get interesting. One might say: in stage 4, methodology is slowly abandoned as inspiration takes over. The sparks in the illustration represent little aha-moments that occur when the interdisciplinary expert suddenly notices a new connection and discusses it with the rest of the team. Needless to say, this phase needs a lot of **communication**, but also some moments of rest and empty time to let all the new information and ideas sink in. It is important at this point that all team members take care of themselves and of each other, remain open and clear about their boundaries, but also their hopes and wishes for the project and their positions within the team. This is all part of developing **self-authorship**. Furthermore, as this part of interdisciplinary research is a **creative** process, intuitions should be given ample space to be pursued, even when they are not yet well-comprehended. Hence, the fruitfulness of this process relies on collective trust and **commitment**, particularly when friction occurs. Be aware that friction is often a signpost for an epiphany waiting further down the road if you have the courage to confront the discomfort and stick through tough conversations and maybe even heated disputes. In such situations, it is important for you to realize that your teammates are sitting in the same boat with you. Make sure that you give each other as much **critical** feedback, but also as much respectful space as needed to let thoughts and ideas develop and take shape.

5. Stage 5 is the emergence of the interdisciplinary perspective and what we loosely refer to as "the magic" (we return in further detail to it when we discuss interdisciplinary methodology). This part of the interdisciplinary research process can be seen as the 'break-through' that results from the accumulation of smaller aha-moments and insights. It is usually felt to result in a broader and deeper, more holistic understanding that can in hindsight often change the perspective on the entire previous process and leads researchers to return to earlier steps. For instance, some findings need to be reconsidered in a new light, requiring further research or picking up on discarded information. This should be done thoroughly until the team feels on the same page regarding the interdisciplinary view.

6. The last phase is one where **creativity** and **critical** thinking come together in **collaborative** writing. This does not mean that everyone needs to be involved in the writing itself; however, everyone should be involved in feedbacking, editing and refining the work. This process can be tedious and require repeating several previous research phases, just as in phase 5. This means that persistent **commitment** is much needed and often **courage** is key to producing a clear and convincing paper. It may be tempting to back down a little when considering the perspective of more traditional, disciplinary readers, especially if your team's insights challenge existing views of all the involved disciplines. However, if you believe that you have made an advance together, you need to stand up for your work and communicate your findings with **confidence**. At this point in the process, you probably know and trust each other well enough in the team to be able to provide mutual support and encouragement when needed.

7. Last, but not least, you will enter a peer review process that is not quite like any other, given that there are no 'allround' experts on the work that you have produced. You will probably receive confused, sometimes doubtful or maybe even outraged responses, you may have to explain parts of your thought process over and over again and you may be facing hard decisions on where to compromise in light of reviewers' criticism, and where to keep on pushing your arguments. Here, you need to be skilled and **empathic communicators**, both within the team and beyond, and you need a good deal of **self-authorship** and **reflection** to make good decisions together. Iterations of previous phases in the process are integral to this part of interdisciplinary research, especially since interdisciplinary understanding often comes with the insight that a different question needs asking, or a disciplinary perspective has been neglected that had not previously been considered relevant. Due to their innovative nature, interdisciplinary answers or solutions tend to inspire further questions, problems and thus form the beginning of follow-up research projects.

METAPHORS

Communicating across disciplines through metaphor
Humans have been using metaphors in spoken and written language for centuries, to communicate, exaggerate, insult, entertain, and to convey ideas and sensations that are hard to put into words (Lakoff & Johnson, 1980). It is this function of metaphors, to communicate hard-to-express ideas, that is of particular interest for the field of interdisciplinarity. However, metaphors are more than just a possible interdisciplinary tool. Metaphors are a specific type of figurative language which we all use in everyday speech, often not realising that common metaphors have a figurative meaning instead of a literal one until we are communicating with someone who doesn't share our native language. In English, for example, it's common to describe shifts from joy to sadness as a rollercoaster, without realising that we are using our shared understanding of the experience of riding a rollercoaster to explain the sensation of emotional highs and lows. Anything can be the tip of the iceberg, anyone can be a black sheep or a fish out of water, metaphorically speaking.

Metaphors work through comparison. In a metaphor, one *unknown* thing is described as being another *known* thing (Caviola, 1999). The known thing is "a key, to unlock the mystery, or some part of the mystery, of the thing that is unknown" (Oliver, 1994). The metaphorical comparison conveys a lot about the unknown object you are describing, more than it is easy to put into words. Metaphors have been used for insulting put-downs since before Shakespeare - "Thou art a boil, a plague sore, an embossed carbuncle in my corrupted blood" (King Lear, Act 2, Scene 4) still stings! Poet Mary Oliver describes a good metaphor as one that surprises and delights (1994), and Aristotle described a successful metaphor as combining "clarity, pleasantness and unfamiliarity", and leading to shared understanding (Cameron, 2003). Communicating ideas and leading to shared understanding is precisely why metaphor is a useful tool for interdisciplinary teamwork.

The ideas that interdisciplinary teams seek to share are frequently "complex, abstract subject matters" (Heusser *et al.*, 1999, p.47). Metaphors can be used to translate an idea

from field-specific, abstract ('jargon') terminology into a different, more accessible format, which systematically crosses disciplinary boundaries. Caviola explains the use of metaphorical for interdisciplinary thinking as follows: "metaphor combines two preconditions that seem essential to interdisciplinary thinking: a) abstraction from disciplinary limitations b) the possibility of seeing (visualizing?) properties shared by several disciplines." He further explains that the integration of two elements on the basis of both difference and similarity defines the structure of metaphor. This statement nicely illustrates how closely metaphorical and interdisciplinary thinking are related: it accurately describes the core practice of Repko's interdisciplinary method, which you will encounter more thoroughly in part III of this booklet.

Finding a metaphor that translates between different disciplinary formats of thought is not easy, particularly because metaphors do rely on shared understanding to create more shared understanding. If you describe a TV series as a rollercoaster to someone who is unfamiliar with the common metaphor and is terribly afraid of rollercoasters, they might leave the conversation without any shared understanding. However, when done right, metaphors can spare you much harder work. Once you have established a working metaphor, you can use it as a playground to help you tie together and make sense of the different disciplinary viewpoints in interaction. As a cherry on top, this helps not only the interdisciplinary writer, but also any readers of your written work. Remember that interdisciplinary writing faces the challenge of reaching readers from multiple disciplines, hence it should strive to be as accessible as possible. Eppler emphasizes that especially with modern information technology, metaphors can help organize information meaningfully into visual representations, such that a viewer can relate what is new to what he or she already understands (Eppler, 2003). Information technology is one of the newer ways in which to create metaphorical understanding, yet metaphor can encompass a wide variety of forms, from natural elements ("Plato's cave") through everyday life items ("Ockham's razor"), to geometric figures ("the circle of life"). Even mathematicians are constantly working with metaphors. This is true to such an extent that metaphorical thought has been argued to underlie the very workings of mathematics (Lakoff & Nuñez, 2000) and any understanding of it (Thomas, 2007). This dependence especially shows in how probability and statistics are communicated and taught (slices of cake, gamblers and dice rolls).

UP TO YOU

If you want to know more about metaphor, it is a great interdisciplinary topic to read up on! There is a whole field called "metaphor science", which involves a variety of disciplines such as linguistics, neuroscience, psychology, philosophy, sociology, literature, politics, ... can you find a discipline that is not interested in studying the use of metaphor?

A metaphor for interdisciplinarity

After introducing the metaphor as a tool that can help us think about abstract concepts, how better to demonstrate its use than with the example of interdisciplinarity itself? To that end, we present to you the story of the blind men and the elephant, an

BLIND MEN AND THE ELEPHANT

A Poem by John Godfrey Saxe
(1816-1887)

It was six men of Indostan,
To learning much inclined,
Who went to see the Elephant
(Though all of them were blind),
That each by observation
Might satisfy his mind.

The First approach'd the Elephant,
And happening to fall
Against his broad and sturdy side,
At once began to bawl:
"God bless me! but the Elephant
Is very like a wall!"

The Second, feeling of the tusk,
Cried, -"Ho! what have we here
So very round and smooth and sharp?
To me 'tis mighty clear,
This wonder of an Elephant
Is very like a spear!"

The Third approach'd the animal,
And happening to take
The squirming trunk within his hands,
Thus boldly up and spake:
"I see," -quoth he- "the Elephant
Is very like a snake!"

The Fourth reached out an eager hand,
And felt about the knee:
"What most this wondrous beast is like
Is mighty plain," -quoth he,-
"'Tis clear enough the Elephant
Is very like a tree!"

The Fifth, who chanced to touch the ear,
Said- "E'en the blindest man
Can tell what this resembles most;
Deny the fact who can,
This marvel of an Elephant
Is very like a fan!"

The Sixth no sooner had begun
About the beast to grope,
Then, seizing on the swinging tail
That fell within his scope,
"I see," -quoth he,- "the Elephant
Is very like a rope!"

And so these men of Indostan
Disputed loud and long,
Each in his own opinion
Exceeding stiff and strong,
Though each was partly in the right,
And all were in the wrong!

MORAL,

So, oft in theologic wars
The disputants, I ween,
Rail on in utter ignorance
Of what each other mean;
And prate about an Elephant
Not one of them has seen!
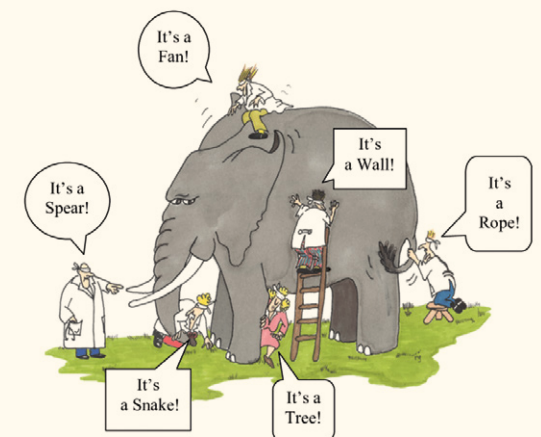
Author unknown

old parable originating from antiquity. As a bearer of meaning, it is especially central in Indian Buddhist writings where it conveys the idea that "truth can be stated in different ways" (Saxe, 2016). The story has since been re-written and used in many languages and many contexts to represent the human tendency of claiming absolute knowledge based on a limited perspective. If you want to be overwhelmed with results, just search for "blind men and the elephant" on Google Scholar.

But here, let us imagine each man to represent a different discipline and the elephant to stand for a particular complex subject matter under scrutiny. Although this particular poetic version concludes in relating the story to theological wars, the blind men and the elephant can also apply to disputes between disciplines. In another version of the story, the blind men encounter the elephant during a visit at the palace. They get into such a loud argument over it that the Rajah awakes from his nap, unnerved by the noise, and shuts them up by asking what made each of them feel so entitled to the truth. This wise man goes on to suggest they put their partial views together, and so they start exchanging their experiences and listening to each other, thus finally arriving at a more comprehensive idea of what an elephant is. This ending gives us a metaphorical account of a successful, integrative interdisciplinary approach. Note the importance of the men listening to one another and collaborating on a definition!

The limitations of a metaphor

The elephant metaphor also illustrates some of the main ideas that underlie interdisciplinarity: the limitation of disciplinary views, the issues arising from monodisciplinary overconfidence, the benefit of collaboration between disciplines, and, finally, the added value of integrating disciplinary views. However, just like with any theory, model, framework or formula, with metaphors too there is a danger of overfitting or overgeneralizing. Let us hence be cautious and take a critical stance regarding the elephant metaphor.

The main point that seems problematic is that the elephant metaphor offers a quite negative take on disciplinary perspectives by representing them as "blind". Understanding interdisciplinarity in terms of this metaphor can therefore result in an unappreciative and unfair attitude towards monodisciplinary experts which is wholly inappropriate. Remember that disciplinary groundwork is prerequisite and foundational to any interdisciplinary effort and is therefore in no way inferior to interdisciplinarity. It simply has different abilities and limitations. Of course, monodisciplinary experts may not be as well-accustomed to acknowledging these limitations, which is precisely why interdisciplinary orientation often helps to expand one's horizon. Still, as an interdisciplinary expert, there is as little reason to feel superior to disciplinarians as vice versa, since we all have limited experience and hence a limited field of vision as human beings. The blindness in the elephant metaphor is therefore somewhat misleading. The narrow-mindedness that it represents should be regarded as a function of arrogance rather than of disciplinary expertise. Whether as an interdisciplinary or a disciplinary expert, your limitations do not need to blind you; in fact, if you get to know them, they can guide you in finding your place and appreciating complementary fields of vision.

Another issue with the elephant metaphor is that it presupposes there being an actual, real elephant that can be "correctly" described and identified. However, this is disputable in regard to subject matters that are studied by academics from different disciplines. For instance, does the phenomenon "stress" compare to an elephant? Is it as

clear-cut? Does it have definite features? And what about an abstract concept such as "human rights"? It is questionable whether we will ever be done discussing what these things mean and entail. This issue does not only concern the abstract, but also extends to more concrete, natural scientific subjects. For instance, take neuroscience. Is it possible at some point to know *everything* about the brain, beyond doubt? Even beyond scientific subjects, something as concrete as a direct sense impression can be questioned on its "correctness".

> **WHAT IS "CORRECT" PERCEPTION?**
> A famous epistemological dilemma (see info box on "epistemology" on page 9 is the question whether we perceive things the same way, even if we use the same words to describe them. For instance, how can I know whether your red is the same as my red? This is often referred to as the "problem of perception" (Crane & French, 2021). I cannot share your experience in any direct, unaltered way, so I cannot really compare it to mine; we can only agree that we mean the same thing when we talk about "redness". However, any descriptions or examples we use to communicate our experiences of "red" are internally consistent associations with the color (such as "it's the same as the color of cherries"), which would still hold for both of us individually, even if between the two of us, the experience of "red" actually differed. So, who is to say that your perception of a red apple is "correct", or mine, or anybody's, for that matter? Note that we are still only talking about "correct" perception amongst humans. Consider the mantis shrimp's ability to see ultra violet, for instance (Thoen *et al.*, 2014), or the dog's world which ranges between blue and yellow, like that of most mammals (Neitz *et al.*, 2001). Who sees the world "correctly"?

In light of these questions, one could criticize the positivist stance implicit in the elephant metaphor, that is, the stance that we can establish and accumulate factual, reliable knowledge; and, most importantly, that we can technically achieve complete and true scientific knowledge of the world through empirical measurement and logical thought. This view is heavily contested by the constructivist counterpart, which claims that we do not discover truth - we construct it, and that logic itself is a human construct. In that view, there is no reliable or accurate way of accessing and grasping "reality", let alone establish knowledge beyond doubt.

Of course, in these points of criticism the elephant metaphor may be taken too literally. However, the point is that finding a good metaphor is not good enough. You also need to work with it! This means to do the fine-tuning and become aware of oversimplifications, inaccuracies and other limitations to the image you are using. Then you can either explicitly point them out, or even better, refine your metaphor.

The flashlight metaphor

To follow up on our example, let's refine the metaphor at hand and imagine the elephant, in the dark. In any case, this is a more intuitive way of imagining unknown things. To get a good look at the elephant, one must now point at it with a flash light, which we can choose to represent a discipline's means of investigation. However, from

Influence of lighting angle on perception (Yamashita, 2012)

Can you imagine any explicit understanding of a subject without a framework for your thoughts? Consider disciplinary elements such as: vocabulary to talk about the subject, basic assumptions and doctrines to build on, methods and techniques to develop ideas, criteria to scrutinize them, etc.

If you want to see more beautiful installations using light and shadow, look up „shadow art". How can these art works help you think about (interdisciplinary) research?

one angle alone, we get a partial and one-sided view of the elephant, which can lead to an incomplete or even misleading idea of the whole elephant. It figures that adding a few more flash lights from different angles and combining the resulting views is probably helpful. Now, instead of portraying disciplinarians as blind, we acknowledge their importance and focus on the specificity of their perspectives, while still motivating the interdisciplinary approach.

UP TO YOU

Of course, the flash light metaphor too must have its limitations. We leave it to you to think about them and play around with the image to test how far its metaphorical value holds up to the purpose. If you do so, and you end up trying to further refine the metaphor, you might find yourself understanding interdisciplinarity better and better in the process. This, and the appreciation of metaphor as a tool to understanding, are what we hope for you to take from this section. Next, we will turn to the origins of interdisciplinarity.

A BRIEF HISTORY OF (INTER)DISCIPLINARITY

"There and Back Again"

At universities, the modern disciplines currently dominate learning and knowledge production. However, education in fact originated as a unified approach, while disciplinarity in general, as well as the shape and content of individual disciplines, are the result of fairly recent developments. The focus on disciplines in universities has led to a variety of effects, including the specialization and fragmentation of knowledge production. This has eventually resulted in some of the present struggles with disciplinary isolation, and the consequent start of increased initiatives moving back towards a more holistic way of thinking.

But more on that later – first, let us recap. How did we get here?

Origin of disciplines

In Roman and Medieval times, the term 'discipline' was applied to a limited set of professions, such as medicine and law, in recognition that these required the learning of specialized information (Klein, 1990). Before being trained as doctors or lawyers, all students received the same general education.

During the scientific revolution **of the sixteenth through eighteenth century**, when testing theories through careful observation, reflection and/or experimentation became more common, separate fields with specialized scholars, equipment and methods emerged. While the idea of science as a unified endeavor was still embraced, in practice most scientists knew only one field of inquiry well. Discussion and exchange of detailed information became more and more restricted to separate fields of activity. This was further consolidated when three revolutionary learning techniques (writing papers, grading and examination) were being used **from 1750 onwards** with the result that teaching and knowledge production in each specialized field far outdid that of any other approach to learning devised by previous civilizations (Klein, 1990).

Specialization of disciplines

Gradually, the university became the home of specialized communities of scientists which developed deeper understanding leading to major advances in our understanding of the world **during the nineteenth and twentieth centuries**. The rise of scientific specialties also caused competition for university resources and the emergence of faculties and departments with disciplinary power and self-interest. Each of these faculties developed specialized education programs and research laboratories.

Our current academic disciplines saw their origin in the **nineteenth and early twentieth centuries** (Repko *et al.*, 2020). In addition, disciplinary knowledge and research became more linked to societal improvements (social sciences) and industrial concerns (natural sciences). Starting **about a century ago** we can clearly discern disciplines with three key characteristics that are currently still associated with the word "disciplinarity":

1. Deciding what is taught through the departmental structure
2. Deciding what is good research through specialized journals managed by disciplinary associations

3. Deciding who gets hired and promoted through decisions by both departments and journals

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REDUCTIONISM VS. HOLISM & ANALYTICS VS. SYSTEMICS

▶ **Reduction (from Latin *reducere*, which means "to bring back to") is the idea that something can be brought back to something else** (van Riel & Van Gulick, 2019)**. In the case of science, reductionism claims that theories can be brought back to, and can hence be explained in terms of simpler theories. For instance, a reductionist in regard to mathematics might say that mathematics can be reduced to the laws of logic or set theory. Most commonly, "reductionism" in the sciences refers to the idea that all sciences can be reduced to the laws of physics** (Ney, n.d.)**. Note that consequently, this view holds that *all* phenomena (including love, consciousness, belief, beauty, you name it) are in the end physical phenomena. Think about this: how is scientific reductionism compatible with humanities such as arts, philosophy and literature?**

▶ **The opposite of reductionism is holism, indicating that understanding a system can be unwderstood in terms of its constituent parts and their interactions. Disciplines such as cybernetics and systems theory embrace a non-reductionistic view of science. Sometimes, this means to explain phenomena at a given level of hierarchy in terms of phenomena at a higher level of hierarchy. In essence, this is in the opposite of a reductionist approach, where phenomena at a higher level are explained in terms of phenomena at a lower level (such as explaining the replication of a cell in terms of molecular interactions).**

▶ **The opposite of analytic thinking is synthetic thinking in two main characteristics:**
  1) Analytical thinking, often used in reductionism, allows us to comprehend the parts of the situation while synthetic thinking, used in holism, enables us to understand how they work together;
  2) Analysis is concerned with identifying differences, while synthetic thinking is about establishing similarities.

UP TO YOU
As you read on, think about where and how these opposite and often complementary approaches are useful in the interdisciplinary research process! You can note "R/H" and "A/S" at the margins and revisit your notes some months later to see whether you have developed your understanding of the differences in ways of thinking and their uses.

Concerns with disciplinarity and demand for interdisciplinarity
During the process of increased specialization, there have always been those who expressed concerns for neglecting the value of a broad education and the dangers of the increasingly fragmented understanding of complex problems. These concerns spurred

an increasing interest in interdisciplinarity (Newell, 2010a; Newell, 2010b) which led to the origin of interdisciplinary colleges, as well as increased efforts to expose disciplinary students to different perspectives on societal problems (starting with the educational philosopher John Dewey). The common vision in these initiatives was that in education, all separate parts could add up to a cohesive whole again.

However, the reality of education drifted further away from that holistic idea. The isolation of the disciplines from each other deepened, mainly due to predominant reductionist and analytic thinking (see information box on "reductionism" on p.37) and the concerned voices got louder. An example is Becher (1989) who uses the metaphor of "tribalism" to describe the differences in culture and language between the disciplines.

DISCIPLINARY TRIBES
"Men of the sociology tribe rarely visit the land of physicists and have little idea what they do over there. If the sociologists were to step into the building occupied by the English department, they would encounter the cold stares if not the slingshots of the hostile natives... The disciplines exist as separate estates with distinctive subcultures" (Becher, 1989, p.23)

Science and society
Becher's pointed satire of disciplinary tribalism may also convey some disappointment in the power of the sciences: as a result of overly isolated practices, the disciplines had ignored or failed to explain social movements and ideological struggles in societies during the 1960's and 1970's, including the issues of race, marginalized groups, increase in world population, overconsumption, decline in biodiversity, etc. (Becher, 1989). In the 1970's, the new generation of students and young faculty even thought that "the disciplines seemed increasingly irrelevant or even obstructionist to their quest to understand, address and solve the great issues of the day" (Katz, 2001, p.520). In those days, interdisciplinarity was embraced as standing for reform, innovation and progress.

Still, it took until the early 1980's for interdisciplinarity to acquire some academic legitimacy when honors programs were declared to be synonymous with interdisciplinarity by the National Collegiate Honours Society. Thus, interdisciplinarity was linked with quality and rigor. It further gained in popularity as environmental studies embraced interdisciplinarity by combining insights from a variety of disciplines to further extend holistic concepts such as ecosystems (Newell, 2010b, p.362).

Interdisciplinary developments today
Over the past three decades, interdisciplinarity has received further legitimacy as educators increasingly view it as a driver of educational innovation. These innovations include applied learning strategies, like: collaborative learning, inquiry- and problem-based learning, civic education, service learning, studying abroad, etc. In the past two decades, interdisciplinary teaching has mainly been promoted in recognition of complex problems (such as climate change, racism, poverty, nature conservation, social justice, cloning, genetic engineering, future food, climate change, population growth, global citizenship etc.)

As investigation of complex real-world problems has been becoming increasingly

interdisciplinary, new fields and methods have emerged within the natural sciences, social sciences and humanities. Below you can find some examples of these interdisciplinary fields and developments.

Natural Sciences
(for instance: molecular cell biology, marine biology, neuroscience, physics, medicine, …)

▶ Climate studies
   As part of environmental studies, the earth sciences (including oceanography) have started to intensify collaborations with physics, chemistry, biology and the social sciences to improve our understanding of the changes in the Earth climate.
▶ Life sciences
   To further elucidate the molecular events that lead to disease, collaboration between the life sciences, technology and the physical and computational sciences increased. This has enabled the human genome-mapping project as well as current developments in taxonomy (the renewed classification and description of relatedness between all organisms).

INTERDISCIPLINARITY IN LIFE SCIENCES
Basic questions of life are complex questions that require integration of insights from multiple disciplines. Consider the following questions:
How do organisms grow and develop? How do viruses function? How are vesicles transported along the cytoskeleton? What is aging? In what way do bacteria in our intestines challenge and support human health? Why do we need sleep? What is consciousness?

To illustrate how disciplinary perspectives play together in the life sciences, Klein (2010) uses the example of how an organism can be viewed:
"as simultaneously physical (atomic), chemical (molecular), biological (macromolecular and cellular), physiological, mental, social and cultural object". (Klein, 2010, p20)

Social Sciences
(for instance: sociology, psychology, political sciences, economy, anthropology, …)

▶ Cognitive Science
   The field of cognitive science has evolved in response to questions that could not be answered by single disciplines. Today the Cognitive Science Society embraces anthropology, artificial intelligence, neuroscience, education, linguistics, psychology, and philosophy
▶ Area studies
   Examples of such specialized fields that combine relevant disciplines are "American Studies", "the Middle East" or "Brexit in Europe". These new area studies make use of two main approaches:
   ▷ the scientific and analytic approach (quantitative research methodologies using data sets and statistics)
   ▷ the humanistic approach (studies with a focus on people embedded in history, culture and institutions)

The topic of globalization connects both approaches to achieve a more complete understanding of how different regions of the world interact in the economic, political and cultural spheres.

Humanities
(for instance: religion studies, philosophy, music history, literature, (art) history, …)

▶ Digital humanities
   Similar to the social sciences, digitalization has permitted new quantitative approaches to research in the humanities. For instance, literary studies now also employ such measures as word frequency and art history has advanced in analyzing style by using machine learning (see information box on "machine-made paintings".
▶ Media studies
   The rise of new media over the past century (radio, television, personal computers, internet, smartphones) has had a profound impact on how individuals worldwide receive and produce information. These technologies initiated a series of complex transformations that require interdisciplinary studies to fully understand the impact on cultures, institutions and especially on how people live their lives.
▶ Further examples for interdisciplinary fields in the humanities that intersect with the social and natural sciences are:
   ▷ The origin and decline of human cultures
   ▷ global citizenship
   ▷ the effects of natural and man-made disasters

MACHINE-MADE PAINTINGS
To the right, you see a painting in the style of Van Gogh. The machine that produced this picture was trained on pictures of Van Gogh's paintings, such as the one in the middle, and thus learned to transform real-life images such as the one to the left into a Van Gogh painting (Karkare, 2019).

Ongoing discussions about "interdisciplinary"
The developments towards interdisciplinary holistic education also encouraged divergent views about the relationship between disciplines and interdisciplinarity ("are they complementary or are they antagonistic?") (Newell 2010b, p.362). A clear definition of the concept of "interdisciplinarity" was lacking, as it was used by a wide range of discipline-based faculty who were unfamiliar with its origins and characteristics.
The term became increasingly fuzzy (Newell, 2010b, p.363) – even to the point where

interdisciplinarity was considered "so fuzzy" that a university's commitment to it is close to meaningless (Wasserstrom, 2006). To tackle the issue, several interdisciplinary experts (Klein, Newell, Szostak, Repko) began writing reports, textbooks, and articles on interdisciplinarity. From these emerged a consensus about the fundamentals of the field that Newell (2010b, p.363) summarizes, as explained in the information box below.

More information on the definition of interdisciplinarity can be found in the earlier section "Definitions".

FUNDAMENTALS OF INTERDISCIPLINARITY

An interdisciplinary study has a specific substantive focus that is so broad or complex that it exceeds the scope of a single perspective; interdisciplinarity is characterized by an identifiable process that draws explicitly on disciplines for insights into the substantive focus; those insights must be integrated; and the objective of integration is instrumental and pragmatic – to solve a problem, resolve an issue, address a topic, answer a question, explain a phenomenon, or create a new product (Newell, 2010b)**.**

BENEFITS OF INTERDISCIPLINARITY

The introduction already gave you some incentives for being interested in interdisciplinarity. All of these were aimed at you personally, as a possible newcomer to the topic. Now that you are more familiar with the idea of interdisciplinarity, we shall turn to the wider implications of interdisciplinary work, its benefits for universities and, through them, for society as a whole. These are benefits that should be of interest to scholars, institutions and investors.

Innovation

"In the twenty-first century, innovations will arise from problem-oriented research, crossing over traditional faculties and disciplines."
— Mainzer, (2011)

Interdisciplinary research is a source of innovative ideas. Why is that so? Firstly, this is because interdisciplinary research forces everyone involved to think outside the box and work outside their comfort zones. Such out-of-the-box thinking often leads to the most unexpected findings, new understanding and innovative ideas, spurred by confrontation with the unfamiliar. This probably doesn't come as a surprise to you.

However, what may be a more intriguing thought is that working in interdisciplinary teams has a mind-opening effect not only on the academic, but also on the personal level. The personal level is equally challenged because experts from different disciplines are also more likely to bring different personality types to the table. This logic leans on the idea that personality type and disciplinary commitment are intimately connected, a theory that has found increasing support in the educational research field (Smart, 2000;

Chen, 2016) - to such extent, in fact, that some universities recommend a choice of major based on personality type (such as the University of Louisville (2020)).

If different disciplinary experts are likely to have different types of personalities, it follows that interdisciplinary teams tend to be more diverse in their composition. Seeing that diversity has proven to be a driver of originality in teamwork (Scheffer *et al.*, 2017), interdisciplinary teams have an edge over monodisciplinary teams in regard to innovation.

Lastly, there is a two-way relationship between creativity and interdisciplinarity. On the one hand, creative individuals tend to seek out interdisciplinary environments to escape disciplinary restrictions on their unconventional ways of thinking (Kandiko, 2012); on the other hand, unconventional ways of thinking can be facilitated systematically by providing the right environment and methodology. Interdisciplinary teamwork provides both these factors: the methodology that guides the interdisciplinary process[2] pushes researchers to engage with a variety of new input and the collaborative setting requires an open mind and a vivid exchange of thoughts and views. These are fruitful ways to spur inspiration, according to Scheffer *et al.* (2017).

Information exchange and networking

Even at universities with supposedly interdisciplinary orientation there is often a communication gap, if not between disciplines, then between faculties. Besides institutional structuring, the above-mentioned personal differences surely play a role in this segregation. The prevalent physical separation of faculties in different buildings or even parts of a city certainly does not help.

What does help is a strongly interconnected academic community. Strong connections between faculties aid interdisciplinary collaboration, which in turn aids connection across faculties: due to its discussion-based nature, interdisciplinary work requires personal contact between experts from different disciplines. Such diversified networking can bridge gaps and open up communication channels between disciplines and faculties, reviving the information flow throughout the entire social network within and between universities. Such an improved communication culture spurs academic productivity, as disciplines reach out more readily to collaborate. Whether they complement or challenge each other's views, the exchange of ideas more often than not leads to cross-pollination between disciplines. It is also worth noting that interdisciplinary skills are not far from intercultural skills, hence staff members who become confident interdisciplinary experts are more likely to act as confident international networkers (Scheffer *et al.* 2017).

Accessibility

„Writing a textbook for interdisciplinary class purposes demands particular sensitivity to audience perceptions and clarity. Most authors – and readers – are conditioned by their disciplinary cultures, which means differing expectations regarding form, content, and style. Particular attention must be paid to the definition of terms, which may sound self-evident but usually mean different things to different audiences."
— Raento, (2019)

2   For more information on interdisciplinary methodology, turn to Repko's steps in part II of this booklet.

We have mentioned before that interdisciplinary writing needs to be accessible for a wide intellectual audience. Let us consider the implications: this means that a good piece of interdisciplinary writing can be understood and used by any scholar or student. Consequently, interdisciplinary articles are a more effective means of communicating and spreading knowledge amongst scholars than field-specific, jargon-riddled articles by and for experts. Considering that quality standards are by no means lower than in monodisciplinary articles, we can therefore consider interdisciplinary writing a valuable intellectual asset for the entire academic community. Arguably, the accessibility goes even further: the lack of jargon makes it easier for non-scholarly readers or novices to grasp the content, opening up educational resources for a larger part of the world population[3].

This leads us to the next point: as well as accessibility of form, another reason that interdisciplinary articles can be enjoyed by a wider audience is the appeal of their content. In combining different approaches, interdisciplinary articles also combine different interests, hence they are more likely to appeal to a larger variety of readers. In a world of increasing divide and disparity of information, any reliable source of knowledge that can attract a diverse audience and offer common ground for open discussion is a treasure.

Interdisciplinary methodology

Steps in interdisciplinary research according to Repko

Repko and Szostak wrote a number of articles and textbooks on interdisciplinary research and education. Their guidelines are used in many colleges and universities to set up interdisciplinary research projects and to write interdisciplinary papers. In the model below, inspired by Repko and Szostak (2021), ten required steps in interdisciplinary research are organized in three research phases. In general, it is important not to skip any of these steps, but to be aware that in practice, they often overlap or need to be repeated (Van der Lecq, 2012).

Based on such experiences with interdisciplinarity in practice, our recommendation is to use the steps below as a checklist rather than as a schedule to be worked off in the prescribed order. If the suggested order suits your thinking process, that is fine too! Either way, make the method your own. Your creative process will spiral up towards good results if you regularly ensure that all steps receive due attention. Especially after a breakthrough or achievement in one of the indicated steps, it pays to go back and check if other steps need revision.

REPKO'S STEPS

Research Question	▶ 1. Define the problem/ state the research question
	▶ 2. Explain why this requires an inter/multidisciplinary approach
	▶ 3. Identify potentially relevant disciplines and indicate possible contributions of each discipline

Disciplinary Findings	▶ 4. Conduct a literature survey in each discipline
	▶ 5. Identify the defining elements of the relevant disciplines
	▶ 6. Analyze and evaluate the disciplinary insights

Integration	▶ 7. Identify conflicts or differences between disciplinary insights/ views
	▶ 8. Create common ground among insights and between concepts or theories
	▶ 9. Integrate disciplinary insights to construct a more comprehensive understanding and draw conclusions
	▶ 10. Reflect on how an interdisciplinairy approach has enlarged your understanding

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3   Provided that publishers allow free access. A lot of journals require payment from readers in exchange for access to articles. Did you know that journals also receive payment from authors in exchange for publishing their articles? What do you think about this?
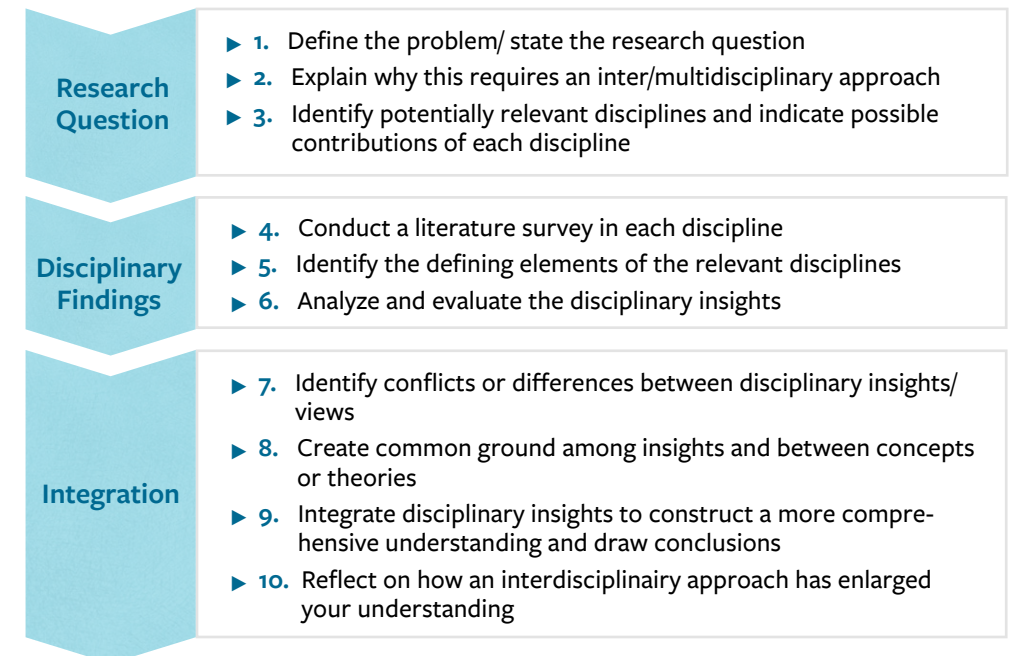
PHASE 1: RESEARCH QUESTION

Step 1 - *Define the problem/state the research question*

Once you have agreed on a topic that triggers your academic curiosity or that demands your problem-solving skills, you need to assess whether it really is suitable for an interdisciplinary approach. This may require a preliminary literature search. Criteria for a suitable topic/question are:

a) **Complex:** It must be complex; impossible to solve from the perspective of just one discipline/approach.
   ▷ examples are: climate change, poverty, aging, Corona crisis, extinction of flora and fauna, biodiversity conservation, political radicalization, fake news phenomenon, digitalization and data privacy, free speech on social media, etc.
b) **Relevant:** It should deal with an unsolved problem or debate, which has relevance. This means explaining why and who should care about the problem. The examples of complex problems mentioned in a) are all relevant to science and society as a whole; however, oftentimes your research question is only relevant to an affected target group, for instance when you conduct a survey at a particular school to help address a particular educational question.
c) **Researchable:** It must be researchable: literature should be available, empirical research doable within the constraints of time and resources available. It also must not be too complex to deal with. Examples like climate change meet the criteria mentioned above but need to be narrowed down to something more specific to make a concrete project out of it.
d) **No disciplinary jargon or bias:** This refers to using a type of formulation or jargon that preliminarily binds the problem to a particular discipline, making it inaccessible or confusing for group members from different disciplines. At the same time, when you use accessible language, you should also realize that you will need to pay attention to definitions. For instance, a concept like "stress" has different meanings in physics, cell biology, medicine, psychology, sociology and economics.

Step 2 - *Explain why this requires an interdisciplinary approach*

Some possible arguments for an interdisciplinary approach are:
▶ Complexity of the topic exceeds the boundaries between faculties (sciences, humanities, social sciences), paradigms, departments or disciplines (biology, chemistry, informatics, mathematics, pharmacy, physics)
▶ Topic receives attention from the disciplines of different group members
▶ No single discipline has succeeded in answering the question

▶ Topic is broad enough for different disciplines to offer an interesting perspective
▶ Approaching the topic from one discipline alone would not allow to achieve convincing and thorough enough answers

Step 3 - *Identify potentially relevant disciplines and indicate possible contributions of each discipline*

Identify disciplinary insights into the problem. Next, select the most relevant 3 or 4 disciplines. In selecting disciplines, you could choose the most dominant insights, or those disciplines that include at least one phenomenon involved in the complex problem of interest. A mind-map may help you to get an overview of the most relevant concepts and disciplinary perspectives. Check the information box on "Mind-Mapping" to inspire your own mind-mapping process.

MIND-MAPPING
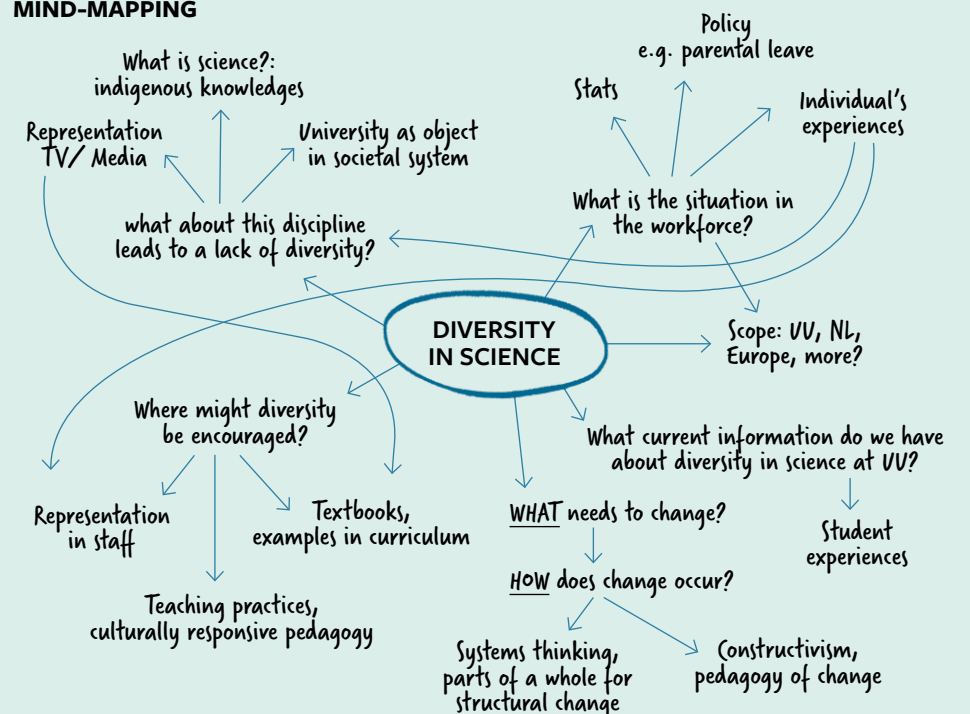
Mind-map on: Diversity in Science
As the author explained: "This was an early brainstorm when I was still trying to think about the breadth of the project, of what we might want to cover in our research, so I wrote down some key questions I had, and resources we might use to look for answers. I used arrows to connect resources across questions, which ended up helping me formulate some key questions for the project as a whole, and resources we might use to answer those".

For further inspiration and an excellent example, you can find a mind-map of Academic Disciplines here: www.gogeometry.com/mindmap/academic_disciplines.html

Once you have decided which disciplines are most relevant to include in your research, you might find it useful to define sub-questions for each of the chosen disciplines. Answering sub-questions in separate paragraphs will provide some information on what discipline may contribute but will also provide structure to your paper.

PHASE 2: DISCIPLINARY FINDINGS

Step 4 - *Conduct a literature survey in each discipline*

Reassure that you have read relevant literature. Think for yourself before you embark on an extensive literature survey. Brainstorm with your fellow students or collaborators, and design a preliminary mindmap, containing the most relevant insights.
Helpful sources of information at the start of your literature research are review articles. Once you have identified the most relevant literature, it is helpful to make a data-management table (see below). A data-management table not only provides an overview of the relevant disciplinary insights, it will also help you in the next step where you will be trying to find common ground.

Table 1: Data-management as developed by Menken and Keestra (2016).

FULL REFERENCE TO THE BOOK OR ARTICLE				
Discipline/ sub-discipline	Theory/ hypothesis	Concepts	Assumptions/ methoadology	Insight into the problem
Name the specific field and specialization	Explain what it entails; describe the relation between the (f)actors that are considered to be relevant (e.g. cause X and effects Y + Z, or the correlation between different (f)actors; or why a certain intervention is thought to be useful in helping to overcome the problem.	Analyze the key building blocks of the explanation or conceptualization captured in the theoretical framework. Give clear definitions of them. Explain which of the (potentially plural) definitions you will take as a point of departure.	Analyze the basic assumptions underlying your theoretical framework. Those assumptions can have an epistemological, methodological, or cultural philosophical nature, i.e. they can be related to our views of reality, and to our views of how we can gain knowledge about that reality, about how science can best study that reality, and about how science can contribute to society. Explain which assumptions you will incorporate or which you reject.	Explain how the theory and the key concepts it entails help to provide more insight in or a possible solution to the problem you are addressing. Also take possible limitations into consideration.

Step 5 and 6 are meant to prepare for a comparison of disciplines, which will facilitate the process of integration in Phase 3.

Step 5 - *Identify the defining elements of the relevant disciplines*

Depending on the author, discipline and journal, it may require more or less effort to identify the following key elements when reading:

- ▸ the author's disciplinary affiliation, which may provide clues about the perspective and assumptions concerning the problem.
- ▸ phenomena addressed, reported findings and key concepts and theories used by the author.
- ▸ research method(s) used or favored by the author.
- ▸ possible biases the author may hold.

A useful way to organize this info per discipline is to create a table in Word or Excel.

Step 6 - *Analyze and evaluate the disciplinary insights*

Analyzing the problem from each disciplinary perspective requires the ability to shift perspectives when one moves from one disciplinary insight to another. It requires viewing the problem of each disciplinary perspective primarily in terms of insights and theories. Creating a table can again be useful to provide insight in the following disciplinary aspects:

- ▸ the theories used in generating insight,
- ▸ the data used as evidence for insights,
- ▸ methods employed and phenomena embraced by insights.

These findings and insights show how each discipline presents evidence that reflects its preferred research methodology and the evidence it considers reliable. Usually in all these cases, disciplinary experts omit evidence that they consider outside the scope of their discipline. In view of the complexity of the problem, often disciplines have a more narrow focus. It is of relevance to keep the broader picture in mind when evaluating the evidence from different disciplines and how the various authors obtained and used their evidence.

PHASE 3: INTEGRATION

Step 7 - *Identify conflicts or differences between disciplinary insights/views*

Conflicting views or just differences may occur at the level of all four categories indicated in the Data-management table: theories, concepts, assumptions and insights. In case of differences these are relevant questions to address (see your data-management file):

- ▸ Which theories are used?
- ▸ Which concepts and terminologies are used to describe the problem?
- ▸ Which assumptions and methodologies are used?
- ▸ Which perspectives are offered to provide more insight in the problem?

LOST IN TRANSLATION
Note that different disciplines sometimes use the same terminology or concept to indicate different phenomena or the other way around. "Stress" is an example for a term which is interpreted differently by physicists, cell biologists, physiologists, behavioural biologists, psychologists, sociologists and economists. Make sure that you understand each other well enough within your team to avoid confusion or misconceptions which would prevent your ability to switch from one perspective to another.

There are three possible outcomes of the process of identifying and analyzing differences:
- There is no true conflict between insights, but the similarity is hidden by terminology or bias
- Insights are different but not contradictory; they present alternatives
- Insights exclude each other

Step 8 - *Create common ground*

This step is the first step required for integration of the disciplinary perspectives. So far, you have mostly been working in a descriptive and evaluative way. You have identified differences between insights, concepts, assumptions and theories of the most relevant disciplines for your topic, and in the process, you have gained a meta-disciplinary overview (read more on meta-disciplinarity in the section on "Definitions").

In step 8, the creative process starts by creating common ground, that is, you start looking for ways to reconcile different insights. Sometimes it is possible to find a common denominator that is hiding behind the differences. But often it needs to be created by setting differences aside and focusing on similarities. (Europe has a long history of wars between nations, but a shared future).

When creating common ground, we identify what elements (for instance, concepts, assumptions, theories, etc.) are shared between the different disciplinary insights. Often, we will see that different disciplines focus on different aspects of the same issue. In the process of creating common ground, preferences for one or the other should be avoided. Creating common ground starts by attributing equal values to different perspectives. It is not about declaring a winner, but about developing a new, more comprehensive view.

The following strategies are helpful in creating common ground (Szostak, 2013):
- *Redefinition*
  involves altering the way a concept is employed by different authors in order to achieve a common meaning. This technique is powerful when authors appear to be disagreeing because they are using the same concept in different ways. When one redefines a concept, and then restates the authors' insights in terms of the redefined concept, the apparent conflict vanishes. In other cases, redefinition resolves only some of the conflict between insights but by clarifying the nature of this conflict sets the stage for the use of other techniques. **The redefined concept(s) is/are the common ground**.
- *Extension*
  involves extending a theory, or the assumptions underlying a theory, so that it includes elements identified by other authors. This technique works best when different insights are potentially complementary. Different authors emphasize different causal factors, but there is no reason why these cannot work in concert. When extending a theory, it is generally best to start from the theory that is already the most comprehensive. If no theory is sufficiently comprehensive, then the interdisciplinary researcher can usefully explore whether there is some common set of assumptions that might allow theories to be combined. **The extended theory or assumption is the common ground**.

- *Organization*
  involves using a map to show how different insights are related. If one author stresses cultural influences on a particular behavior and another stresses personal influences, organization might involve showing how culture influences personal decisions that affect behavior. **The map becomes the common ground**. Note that it will often prove useful to group the phenomena emphasized by different authors into broader categories (such as cultural attitudes).
- *Transformation*
  is a technique for addressing opposites by placing these in a continuum. If one author assumes that agents behave rationally in a particular situation, but another author assumes irrationality, an interdisciplinary viewpoint can appreciate that there is a continuum between perfect rationality and perfect irrationality, identify where on that continuum agents are likely be positioned in a particular situation, and then draw on each of the opposing insights appropriately. **The continuum is the common ground**.

Step 9 - *Integrate disciplinary insights into a whole and draw conclusions*

The final step is the integration of insights on the basis of common ground into a more comprehensive understanding. Show how the combination of different theories and methodologies leads to a better explanation or solution. Within your interdisciplinary paper, see it as a challenge to elaborate on this (difficult) step to trigger innovation. Note that the result of this last step should show that the conclusion you have come to wouldn't have been achieved without an interdisciplinary approach. This is also a good way to check whether you have successfully gone through all the previous steps. If you find that you could have reached the same conclusion by solely consulting one disciplinary perspective, this is a strong indicator that you should go back to see whether you need to carry out any of the steps 1 through 8 more thoroughly.

Step 10 - *Reflection*

In this final step the idea is that you reflect on how an interdisciplinary approach has enlarged your understanding of the problem. To structure your thoughts, you could focus on the following questions (Repko *et al.* 2020):
- How has this research challenged your bias toward the problem? It is important to realize that disciplinary work is often skewed by predispositions, biases and possible misconceptions. Therefore it is of relevance to critically evaluate one's own work as well as that of others on the presence of such biases.
- How has the research process influenced your perception of disciplinary perspectives? Here you can elaborate on your awareness of the limitations and benefits of the contributing disciplines. As interdisciplinary work requires a careful evaluation of disciplinary insights for their potential contributions, it is of importance to indicate whether you developed confidence in your ability to evaluate the value of disciplinary insights for interdisciplinary purposes.
- How has an interdisciplinary approach enlarged your understanding of the problem as a whole? In the current approach you practiced the main steps which are essential

to achieve a more comprehensive understanding of a complex problem, such as critically analyzing disciplinary perspectives, identifying how these insights conflict, create common ground and to perform integration. All this constitutes a cognitive advancement over disciplinary work as it reveals some essential activities required for interdisciplinary work, such as the power of perspective taking and the critical and creative processes of finding common ground and integration.

▶ How is an interdisciplinary approach applicable beyond the classroom? Traditional (disciplinary) ways of generating knowledge and framing public discourse about the complex issues of our time are no longer adequate. Interdisciplinary approaches usually allow a more comprehensive insight and a more satisfactory solution to complex problems. A useful exercise could be how you would describe the relevance of your interdisciplinary experience in a job interview

SYSTEMS THINKING

The methodology of Repko's steps is one of the most frequently used strategies in interdisciplinary research and education when it comes to approaching, analyzing and solving complex problems. Systems thinking is another widely used strategy to approach these types of problems (from biological, environmental, economic and humanitarian to medical, etc.). Below, a number of aspects of the systems thinking approach are described. We will discuss what a system is, provide a short characterization of systems thinking, cover the perspectives included in systems thinking and some key words that are often used. Finally some similarities between Interdisciplinarity and Systems thinking will be addressed. But first, let's start with the basics.

What is a system?

The word "system" is one of the most loosely used expressions in everyday language as well as in academic literature. Systems are here defined as a functionally related assemblage of interacting, interrelated, or interdependent elements forming a complex whole. Hence, we can say that at its most basic, a system is the sum of the interdependent parts which interact dynamically with one another for a specific purpose. Such a purpose differentiates a system from a loose collection of elements in that it binds the elements in functional interaction.

You have surely encountered a variety of concepts which fall under the definition of "systems", such as natural systems (a cell composed of interacting macromolecules and organelles, a human body with interacting organs, a population of individuals, an eco-system with interacting species); human-made systems (ranging from high-tech chips, an airplane, to global commercial conglomerates), and also conceptual systems (like evolution, policy or ethics).

QUICK CHARACTERIZATION OF SYSTEMS THINKING:
"Seeing the whole beyond the parts and seeing the parts in the context of the whole".

What is systems thinking?

Systems thinking can be interpreted in different ways: as a methodology to analyze complex interactions of the components within systems; as a language which allows different disciplines to communicate in order to achieve understanding of complex systems, and finally as a cognitive skill. Below we will mainly focus on the first interpretation in which systems thinking analyses how the different elements interact to achieve the system's purpose or output. In doing so, systems thinking recognizes each part as significant on its own and as required for the system to function. However, it is important to emphasize that systems thinking examines systems holistically. It does not focus on individual parts in order to understand them; instead, it focuses on how these parts act together in networks, how systems work over time and how different systems hang together within the context of larger systems. Hence, a key aspect of acquiring a coherent understanding of complex phenomena is the ability to think *back and forth* between the system as a whole and its components. In this respect, Verhoeff *et al.* (2008) included thinking backward and forward between general system models and concrete biological objects and processes as an explicit element of systems thinking.

System map

An analytical tool of systems thinking is the 'system map', which is an illustration of all parts of the system (or complex problem) and the causal relationship among them (which part influences others). Clearly a systems map helps to visualize the system as a complex whole. The illustration below shows the different parts involved in temperature regulation (homeostasis) in warm-blooded organisms).
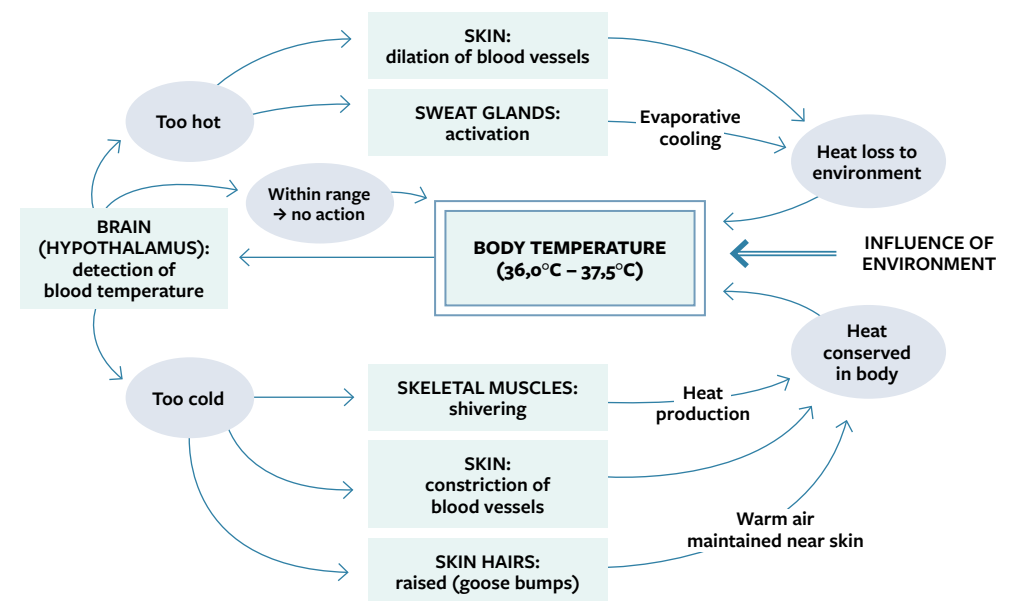
System map of temperature regulation in mammals. Elements involved in maintenance of body temperature are: the brain (hypothalamus for detection of body / blood temperature), the skeletal muscles (shivering) and the skin with its blood vessels, sweat glands and hairs.

Often, the different elements of a complex problem are studied by different disciplines. Drawing a system map and locating the relevant disciplines for each element may enable the researcher also to identify other relevant disciplines or other disciplinary parts of the problem that were not initially obvious.

Modeling systems

In a number of studies, the importance of (mathematical) modeling in the analysis of systems is emphasized (see also Verhoeff *et al.* (2018) and Gilissen *et al.* (2020)). The use of modeling often allows insight in unexpected or counterintuitive events that may characterize the behavior of a system. The idea behind the importance of comprehending *how* the parts interplay to form a whole is that a system can only work efficiently when each element feeds into and provides feedback to other elements of a system. This view assumes a state of interdependence in which even the smallest part of the system deserves consideration. In an ecosystem, for example, when soil bacteria begin to die off, water purity will go down and food supply will be disrupted, ultimately affecting larger animals.

SYSTEMS THINKING AS A COMPETENCY
In the present section, systems thinking is defined and discussed as a process. However, in the literature it is also regarded as a competency. As such, you will encounter it again if you read the section "Enrich Yourself" in part II of this booklet.

Hence, not only interconnection, but also the resulting delicacy of a functional balance is an important consideration for systems thinking.

Levels of magnitude

As experienced in the video "Powers of Ten" (see information box), systems can be discerned at different levels of magnitude. In biology for instance, these can reach from macromolecules, organelles, cells, organs, organisms, and populations up to ecosystems and the biosphere. At each level of magnitude, the dynamic interaction of the system's constituent parts can be studied, modelled and influenced to raise complex questions. This means that as researchers, depending on where we direct our focus and how we formulate our questions, we can zoom in (how do organelles within a cell interact to achieve a functioning cell under different circumstances?) and out (how does an increase in atmospheric CO_2 affect the overall functioning of ecosystems and the entire biosphere?) to define a system and its elements. In addition, our questions can address interactions between different levels of a system, such as: What is the influence of specific genes (and their mutations) on the behaviour of organisms?; What is the influence of a specific soil bacterium on the health status of different species in an ecosystem?; or: How did a particular event (such as 9/11) influence the interaction between different cultures?

POWERS OF TEN
Have you ever watched the video "Powers of Ten" by Charles and Ray Eames (Eames, 1977)? It starts with the image to the right and takes you on a journey through all levels of magnitude we are able to scientifically observe and study. As you watch it, note how elements form a system and how such a system in turn constitutes an element of a bigger system, and so on. At any level of magnitude, you can identify systems. Hence, nothing is a system or an element by nature – it depends on the perspective you're taking. Keep this in mind when you apply systems thinking in intellectual challenges. If you don't forget about the Powers of Ten, you can make the zooming in and out your mental tool to place the concepts and ideas you are dealing with in relation to one another.

Thinking in Powers of Ten, eamesoffice.com

Tip for Teamwork:
It can often spare you some cross-purpose communication if you identify together what level everyone is thinking on.

Complex systems today

The world has never been as evidently interconnected as it is today where complex systems move more and more to the foreground due to such processes as globalization, population growth, climate change, scientific and technological advances, loss of biodiversity, etc. Multidimensional feedback loops affect trades, policy changes, health states of individuals, populations and ecosystems. In all these fields, systems thinking is increasingly recognized as an important skill to tackle complex problems when the balance of a system is lost. Hence, systems thinking is also being applied in an increasing number of research fields (including biology, health sciences, earth sciences, economy, psychology, sociology, sustainability and technology).

A COMMON ASSUMPTION IN SYSTEMS THINKING AND INTERDISCIPLINARY THINKING
An underlying assumption in systems thinking is: "The whole is more than the sum of its parts." This is why it works so well with interdisciplinary thinking: an interdisciplinary solution is more than the sum of its disciplinary solutions to address a complex problem. Could interdisciplinary thinking be considered a particular kind of systems thinking...?

Historical context

Systems thinking, as it developed in the last century, is a departure from the long-standing way in which scholars traditionally attempted to understand phenomena. In particular, there is a poignant contrast between systems thinking as it emerged in the 20th century and its predecessor—the scientific reductionist approach that pervaded Western thinking since the time of René Descartes in 17th century Europe.

According to reductionism, research had to conduct analyses in the form of breaking a complex thing into smaller parts in order to gain a better understanding of it. Understanding the smallest components in isolation from each other was believed to enable the analyst to know the sum total, the whole. As the relation between parts was thought to be defined by simple cause-effect relationships, the defining characteristics of a system had to exist in its parts.

In contrast to the reductionist approach, systems thinking is a holistic or systemic perspective which claims that the whole is not the sum of its parts but rather is a product of the interaction between all parts. Accordingly, the only way to fully understand a system is to understand its parts in relation to each other and to the whole and recognize that the characteristics of the whole cannot be found in the isolated parts. In such cases, a synergy is observed when a new characteristic of a system emerges from the interaction between its elements. Therefore, in direct contradiction to the reductionist view, systems thinking holds that once the system is taken apart into its elements, the defining characteristics of the whole are lost.

To provide an overview, in Table 2, reductionist thinking is contrasted with systems thinking, comparing the ways in which reductionist- and systems thinking approach systems with respect to: the relationship between whole and parts, how parts interact, what the defining characteristic of a system is and how the functioning of a system could be understood.

Table 2: Contrast between reductionist- and systems thinking as indicated for a number of perspectives.

PERSPECTIVE ON:	REDUCTIONIST THINKING	SYSTEMS THINKING
Whole & parts of a system	The whole can be broken down into its parts and put back together from its parts	The whole emerges from the interaction among its parts; the whole is more than the sum of its parts
Interaction and inter-relation between parts	Parts are related to each other through a simple cause-effect relationship	Parts are related through complex multiple influences, factors and feedback-loops
Defining characteristic of the system	The defining characteristics of a system exist in its parts.	The defining characteristics do not exist in its parts, it emerges from the interactions.
Understanding its functioning	Understanding its parts in isolation is sufficient to fully understand its functioning as a whole	A holistic perspective is required to fully understand its functioning often characterized by emergent properties that are based on the intricate interactions between all parts

In the life sciences reductionism has been very successful: examples range from the purification of proteins, DNA and RNA and the study of their structures and activities, to the sequencing and analysis of whole genomes. While the reductionist approach will continue to be of relevance in biology and the life sciences in general, there is increasing interest in understanding the properties of the systems that arise out of the interactions of, for instance, biomolecules.

Key terms in systems thinking

Some of the key terms that you will often encounter when reading about systems thinking or processes related to it are the following:

▶ Interconnectedness
▶ Synthesis
▶ feedback loops
▶ emergence and synergy
▶ systems analysis & systems-mapping
▶ self-organization

We briefly address each of these below.

Interconnectedness

…can be well understood through the example of ecosystems. Ecosystems consist not only of animal and plant life forms, but also of the fungi and soil bacteria, the environmental structure (water and air quality) and the spatial requirements. All these elements interact in myriad ways. When one of them is affected, the interaction between all elements will change and the functioning of the entire system will be affected.

Synthesis

…is essentially the result of an analysis that integrates the whole with the interaction between its component parts to understand how all elements work together to allow the system to function as a whole.

Feedback loops

…depict how the parts interact with and inform one another, which provides a perspective on the relationships between different elements within the system. An important feature of feedback is that it provides information to the system as a whole regarding how it is doing relative to a desired state or purpose. In addition, positive feedback loops usually amplify and enhance the product of interaction, whereas negative feedback loops serve to stabilize a system.

Emergent properties

…are defined as novel properties that come into existence as a function of the arrangement and interactions of the elements of a system and which become apparent at a higher level of analysis than that on which they form. Interestingly, the properties that emerge from the interactions between the components of a system do not belong to any particular part of the system. Emergent properties are typical for, but not unique to, life. For instance, a set of bicycle parts allows you to cycle to a specific destination if they are

arranged in a specific way. The property of serving as a means of transportation emerges at the level of the whole bicycle, whereas the function of each bicycle part contributing to that property must be considered on a more detailed level. In general, emergence can be understood with the expression: "the whole is more than the sum of its parts (Aristotle)", which is also an assumption that systems thinking builds on. For convenience, this expression can be summarized with the buzzword 'synergy'. Synergy is defined as the interaction or cooperation of two or more substances, individuals, disciplines, organizations or other agents to produce a combined effect greater than the sum of their separate effects. An example in a purely physical sense is a "cocktail" of drugs which may be more effective than the sum of the effectiveness of each of the separate drugs.

> **CONSCIOUSNESS – AN EMERGENT PROPERTY?**
> Neuroscience has been puzzling over the phenomenon "consciousness" for as long as the field has been aware of its existence. One of the most widely celebrated (and disputed) current explanations accounts for consciousness as being an emergent property of complex systems such as the brain (which is regarded as a complex system of integrating neurons). In other words, consciousness is thought to be a side effect of how the brain works. If you want to read an example of this view, check out the article "Phenomenal Consciousness and Emergence: Eliminating the Explanatory Gap" by Feinberg and Mallatt (2020).

Systems analysis & systems mapping

...is what systems thinking does: the complex and dynamic interactions between the parts of the system are analyzed, rather than focusing on individual components in isolation. The goal is to understand how parts relate to the whole. Often, systems mapping is used to depict dynamic interactions between elements and behaviors within the system.

Self-organization

...is a process by which a system—several components together with interaction rules—becomes ordered in space and/or time. Self-organization is usually distinguished from self-assembly because self-organized (biological) structures rely on a continuous input of energy to be maintained. The principles of self-organization, developed in physics and engineering, are combined with mathematical modeling in order to predict the (self-organizing) behavior of networks of interacting components. This approach is currently providing many novel insights into biological systems, as is explained about research involving the making of a large swarm of tiny robots (see information box): "Biological collectives involve enormous numbers of cooperating entities – whether you think of cells or insects or animals that together accomplish a single task that is a magnitude beyond the scale of any individual".

**Relationship between Interdisciplinarity and Systems Thinking**

One of the founders of interdisciplinary studies, William Newell, emphasized that an interdisciplinary approach is justified only when investigating complex systems (Newell, 2001). In his paper, he offers building blocks for a common language to be used in the fields of interdisciplinarity and systems thinking, both of which aim to increase our understanding of complex systems and the associated phenomena (Newell, 2001).

His reasoning in favor of involving different disciplines is that most phenomena arising from complex systems are multi-faceted, i.e. emerging from sub-systems within which different components and/or kinds of relationships dominate. This calls for the application of various disciplines that have been developed precisely to study the relevant individual facets or subsystems. Interdisciplinary study can integrate these necessary insights into a more comprehensive understanding. Synthesis or integration of insights allows researchers to capture the dynamic, often non-linear relationships between elements to grasp self-organizing characteristics and behavioural patterns of the complex system as a whole.

> **KILOBOTS – A COMPLEX KILO OF SIMPLE ROBOTS**
> A team of researchers at Harvard has built the so-called "Kilobots", a swarm of a thousand little robots which, by themselves, appear entirely unable to do anything exciting (Wyss Institute, 2014)**: they can move, sense another robot and are programmed with a small set of simple rules on how to react upon such an encounter. Together, however, they can form any shape you request via an infrared light, simply by trial and error, scurrying around until all robots are satisfied with their position. This robot swarm is an example of "collective artificial intelligence". But Kilobots was not only devised to advance robotics and AI; it also informs biologists in their efforts to understand the workings of what may also be called "superorganisms"** (Wyss Institute, 2014)**. Superorganisms are self-organizing groups of individual organisms that act together in such unity that they appear to form a larger entity of its own. You can read more about this in Wilsons's book "Evolution for Everyone"** (Wilson, 2007)**. The topic becomes truly fascinating once you ask yourself: What can we learn about our own species if we regard humans as a superorganism?**
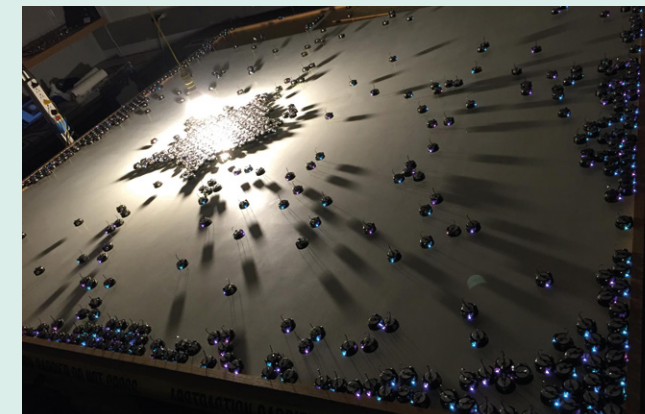
For more information on the Kilobots project and links to articles about the new scientific insights it has informed in a variety of fields, you can visit https://ssr.seas.harvard.edu/kilobots

The Kilobots swarm forming a star.

About the magic

You may have noticed that while it is quite clearly outlined how to perform steps 1-8 of Repko's methodology, step 9 remains a little mysterious. "Integrate insights" sounds good, but how exactly should this be done? Most interdisciplinary theory remains vague on this step, and we think that this may be for a good reason: it is a creative step by definition (it entails crafting something new out of a combination of elements) and creativity cannot be "proceduralized". However, this does not mean that step 9 should be glossed over and left up for the researchers to struggle with. After all, this is the point at which research becomes truly interdisciplinary! Everything leading up to it is, strictly speaking, still multi-, cross-, or meta-disciplinary work. Hence, this section is dedicated to interdisciplinary integration. In Figure 4 (on p. 28), this step is portrayed as a flash of light following several smaller sparks. Amongst the team behind this booklet, we have come to refer to it as "the magic".

Talking about the magic in interdisciplinary research is much like talking about falling in love: You have to experience it. From our experience with interdisciplinary work, we would describe it as a flow state in which your thoughts as a team seem to connect in an intuitive, enthusiastic way, where knots resolve, puzzle pieces fall into place or bigger pictures suddenly come together and put everything into a new light. This may sound cheesy or phantastic, but remember that it is usually the result of hard work and dedication, and more often than not the magic occurs after deep and demanding struggles, often even frustrations. Hence, the moment of break-through can be accompanied with emotions. Generally, we have experienced this magic as a result of the careful building of interpersonal relationships and shared understanding regarding our respective angles on key concepts. Furthermore, during the process leading up to the magic, meta-disciplinary thinking and shared self-reflection, as well as patience, endurance and honest communication are key. Hence, especially respectful and curious interpersonal relations are an aspect that we wish to highlight as extremely conducive to the magic.
The other aspect that we want to emphasize may point to the reason that step 9 remains ominous in the literature. Namely, prescribed procedures only get you so far; you cannot force the magic to occur. What you can do is to mind your attitude. Try to remain open for the unexpected (Maloney & Conrad, 2016), seek nuance, read between the lines, listen to your own and your teammates' intuitions, try and keep an eye out for the little sparks of inspiration and stay sensitive to moments that require you to suspend your disbelief and "roll with it" for a while (Townsend & Mikkonen, 2019). Besides fine-tuning your own sensitivity for the little sparks that may lead to an epiphany, and giving your teammates space to follow their sense for serendipity and inspiration, you can do a number of concrete things to make room for the magic. We do not claim to know exactly how to create the optimal conditions, but we do believe that genuinely trying out any of the following suggestions might surprise you.

Making room for the magic

Regular casual encounters

Regular occasions for casual and open dialogue are the fruitful ground for little seedlings of ideas to flourish and unfold their potential. It is widely known that informality is crucial for idea generation and development. Many of the best ideas in the history of academia have emerged from coffee corner conversations or the occasional night at the local pub.

Schedule in empty time

We do need time to think. We do need time to digest. We do need time to misunderstand each other, especially when fostering lost dialogue between humanities and natural sciences. We cannot continuously tell you what our science means; what it will be good for; because we simply don't know yet. Science needs time.
— *The Slow Science Academy, 2010*

Sometimes, everything happens when nothing else happens. Make sure to schedule in some of these non-happenings - individually or together, ideally both. The ground rule during empty time is to give it no intention at all, not even conversation. To help you dedicate the time without having to watch it, remove all clocks out of sight and set one alarm that will remind you when your empty time is over. Close your laptop and set your phone on airplane mode. In the beginning, doing nothing may be hard. To ease into it, you can start with smaller chunks of time - even 5 minutes are better than nothing! - and/or pick up mindless occupations. You can go for silent walks, preferably in nature, observe people in a park or on the street, read the most unexciting book that you own (it could be a childrens' book), get a coloring book or start knitting. Whatever you do, and whether alone or together, you need to make it explicit for everyone involved that no expectations are being held for this period of time. Conversations or ideas may emerge, or not, and either is alright.

> **AN ALIBI PROJECT TO PROTECT YOUR EMPTY TIME**
> To start a habit of empty time, it is easiest if you schedule regular bits of it far in advance, for instance for the entire coming semester. You can use an alibi in your calendar to avoid having to justify your choice or getting tempted to compromise. Just invent a project, give it a name that sounds important and schedule in fake meetings, both in your own personal calendar and, if relevant, the calendar that others may be able to access. Treat these meetings with the highest priority. This requires some self-discipline! If someone asks you to do anything else during these times, you need to be able to pull yourself together and decisively say: "Sorry, that's impossible, I've got an important meeting scheduled during that time". If you find that hard, it is good to remind yourself that you're not lying. Empty time is in fact very probably the most precious appointment you have scheduled in a day. Whether you do this in smaller portions daily or in larger time slots every few days is a matter of trying out what helps you.

Create an open atmosphere

Room for serendipity can be understood not only in terms of head space and free time, but also in the physical sense. Some institutions and organizations have introduced a creative space to their work environment to enable employees to spend time together within an atmosphere that is free from association with the pressure of the daily hamster wheel. Such a room can be colorful and creative, cozy and relaxing, or simplistic and empty - this depends on the context and the needs at hand. What matters is to set this space apart from usual work life. If there is no such physical space available, there are many simple ways to transform a workspace into a creative space. For instance, changing the lighting, putting on a particular kind of background music, moving tables to the side and sitting on the ground, lighting a candle, taking off your shoes, ... You may note that these changes are met with some social awkwardness at first, but that should only encourage you. The awkwardness marks the boundary to a different kind of social space, and when you overcome it, you can think more freely together. Alternatively, you can always agree to go for a walk instead of meeting in a room.

Diversify materials & methods

Academic work is often highly cerebral, and linked to reading or writing. Whatever you can do to make it more physical is worth a try! Diversifying the materials you are using as thinking aids can encourage the development of an open mindset and new ideas. An increasing body of research shows that the physical space and physical objects that you interact with in it affect how you think and link ideas (Anderson, 2003). If you want to know more about this area of study, you can look up "embodied cognition".

Here are some ideas to help you diversify:
Share a pin board or white board (preferably a physical one in a common space, but you can also use online tools such as miro, google keep, conceptboard or mural), make mind maps, start a notebook in pocket format that is exclusively used to jot down random thought bubbles and ideas, play association & dissociation games (play games in general), provide stress balls and other toys or materials to play with, take breaks to practice juggling, try collaborative writing activities,

EXAMPLE FOR AN ASSOCIATION GAME
Set three containers on a table, each of which holds a different title (you could make one container per discipline or per concept that you have encountered in your research). Cut some paper into little strips or use post-its. For each container, write down as many words as you can think of (one per piece of paper) that you associate with the corresponding label. You may diverge further and further from the label as you keep coming up with words; that is good. Divergence and convergence are equally crucial and integral parts of creative processes. Remind yourself that there is no wrong way to do what you're doing; it is not a task, but an open-ended activity. Once you have collected a good amount of words in each container, start drawing from different containers one piece of paper each and write down at least 150 words on how they relate. Do not actively try to solve a problem or be comprehensive - or even consistent. This is an exercise in abandoning your usual thinking patterns. Instead of writing, you can also play this game together by taking turns in drawing papers and spending 3 minutes talking per round.

PART II
INTERDISCIPLINARY YOU

About part II

This part is about competencies that are integral to interdisciplinary work and that provide a good basis for any student that is looking to expand their horizon. Some of these competencies are crucial for you to be aware of and foster to ensure that you can thrive in and meaningfully contribute to an interdisciplinary environment, such as working in a multidisciplinary team. An overview of these is given in the first section ("Equip Yourself"). As you read through this section, it is important to keep in mind that training yourself to become fit for interdisciplinary environments is a marathon, not a sprint. Patience with yourself, your collaborators and the products you create is crucial; however, through any struggles you encounter, rest assured that the experience you gather in the course of your successes and failures will be rewarding! The rewards come in terms of competencies that we address in the second section ("Enrich Yourself"). This section introduces you to some of the key competencies that you will develop in the course of your interdisciplinary experiences.

Of course, what you bring to the interdisciplinary table and what you take from it are competencies that will inevitably intertwine. Everything you learn through one interdisciplinary experience will impact how well-equipped you embark on the next adventure.

If you would like to read a more condensed version of the most important considerations to contemplate in preparation for interdisciplinary teamwork, you can check out the section "Others Before You" in part III. There you will find 10 tips given to you by a selection of researchers who speak from their own experience with interdisciplinary project work. These tips contain not all, but a lot of the main points we discuss in the present section.

PART II
INTERDISCIPLINARY YOU

Equip yourself: qualities & attitudes
to bring to interdisciplinary teamwork

Effective participation in interdisciplinary teams is not so much a matter of individual traits as it is of learned behavior.
— *Repko et al. 2020*

There are a number of qualities and attitudes that help you work fruitfully in an interdisciplinary context. Here, we have summarized the ones that are deemed most important in the literature. A good interdisciplinary team player should attempt to be curious, collaborative, communicative, creative, critical, flexible, confident in your competence, courageous and committed. We say *attempt to be* because you might think that you do not have all of these traits. That's quite likely, but don't worry! We hold that these are not given traits, they are skills that can be developed. Interdisciplinary teamwork is learning by doing, so you do not have to master these skills already. However, you do need to be willing to actively work on them. This also means being open to feedback, to reflect on your behaviors and practice the aspects of interdisciplinary teamwork that you struggle with. Try not to fuss about upholding some sort of self-image; you have so much more to gain if you have nothing to lose. Keep fueling that mindset, and you'll find a lot of other things running smoother for you! Finally, we also look into how empathy plays into all the other qualities and attitudes.

UP TO YOU
Interdisciplinary teamwork thrives on, and at the same time helps you develop and maintain, a growth mindset. This is a popular concept developed by Dweck in her book „Mindset: The New Psychology of Success (2006). Read through the sentences in the illustration and when you read on, try to recognize the Growth Mindset in all the qualities, skills and attitudes discussed in this part of the booklet!

GROWTH MINDSET
"Failure is an opportunity to grow"
"I can learn to do anything I want"
"Challenges help me to grow"
"Challenges help me to grow"
"My effort and attitude determine my abilities"
"I am inspired by the succes of others"
"I like to try new things"
"Feedback is constructive"

FIXED MINDSET
"Failure is the limit of my abilities"
"My abilities are unchanging"
"I can either do it, or I can't"
"I'm either good at it or I'm not"
"I don't like to be challenged"
"My potential is predetermined"
"When I'm frustrated, I give up"
"I stick to what I know"
"Feedback and criticism are personal"

CURIOUS

"A white rabbit is pulled out of a top hat. Because it is an extremely large rabbit, the trick takes many billions of years, All mortals are born at the very tip of the rabbit's fine hairs, where they are in a position to wonder at the impossibility of the trick. But as they grow older they work themselves ever deeper into the fur. And there they stay. They become so comfortable they never risk crawling back up the fragile hairs again. Only philosophers embark on this perilous expedition to the outermost reaches of language and existence. Some of them fall off, but others cling on desperately and yell at the people nestling deep in the snug softness, stuffing themselves with delicious food and drink. 'Ladies and gentlemen,' they yell, 'we are floating in space!'"

This is Jostein Gaarder in his book "Sophie's World" (1994), describing in essence what philosophers and children have in common. But you don't need to be a child or call yourself a philosopher to cling on to the tip of the rabbit's hairs to wonder about fascinating aspects of life. It is enough to keep wondering about things, to not take them for granted - in other words, **be curious**!

Curiosity makes powerful learners; you will not be able to find a great intellectual who is or was not curious. Take Charles Darwin, Marie Curie, Hannah Arendt, Leonardo da Vinci, Margaret Mead or Albert Einstein, for example. Curiosity means to be tempted by the unknown, to follow an inner drive to explore further and expand your horizon.

Curiosity didn't kill the meerkat.

In your academic development, curiosity is reflected in wanting to **think beyond**, in asking questions and then questioning the answers, like the never-ending game that children so love. If you return to the figure of the funnel of expertise, curiosity can lead you from top to bottom through more and more challenging forms of understanding, and every stage will open up new kinds of questions for you. In your interdisciplinary development, curiosity is a crucial formative force because it allows you to engage openly with perspectives you have not yet encountered, which may often seem incomprehensible, strange, flawed or even ridiculous to you at first sight. Curiosity leads you through that first impression and on to deeper understanding. As a consequence of this, curious people challenge their views of self, others and the world, which is a fundamental part of interdisciplinary work. Maybe that is why, as Repko and Szostak (2021) observe, interdisciplinary work tends to attract those who are, at their core, "intensely interested in the world they live in". This kind of open curiosity is also in part what spurs the development of self-authorship (read further on this in the next section "Enrich Yourself").

Finally, it might be unusual to think of curiosity not as a character trait but a quality that can be trained like a muscle. Still, give it a try! The easiest way to get your curiosity going is by truly listening to what others tell you. To truly listen means to assume that you do not really know what the other wants to communicate because you cannot read their mind. If you question your understanding of what you're being told, you will soon find a whole lot of room for questions, and once you start asking, the game is on!

▶ **Look out for...**
...taking your conversation partners into cross-examination. Asking questions is not the same as questioning. Make sure others are comfortable by posing your questions in an open and inviting manner ("tell me more!") rather than in a nosey or challenging way ("I'm not convinced!"; "justify your claim!").

UP TO YOU
If you want to hear an excellent demonstration of constructive curiosity, listen to how Alan Alda facilitates conversations in his podcast "Clear & Vivid – Conversations about Connecting and Communicating". Another example for an unstoppably curious mind is Alie Ward with her podcast "Ologies", in which she approaches experts who are specialized on fascinating and sometimes absurd scientific niche topics. Her bold and authentic attitude demonstrates that there is no such thing as "dumb questions".

COLLABORATIVE

Collaboration is a hallmark of interdisciplinarity. One reason for this has already been discussed as part of the "definition" section in part I; it is rare that an individual can span two or more disciplines with the necessary expertise to produce respectable interdisciplinary work. However, there is more to such professionality than just disciplinary expertise alone. Interdisciplinary expertise is a skill in its own right. It means to be able to integrate knowledge from different disciplines in a manner that does not take away from the individual disciplinary views but enhances them. No matter whether you yourself want to specialize in such interdisciplinary expertise, or whether you rather want to contribute disciplinary expertise to such collaborations – you need to develop a sensitivity for the different ways of thinking and working in other disciplines than your own. Collaboration also provides plenty of training by exposing you to unfamiliar points of view (Graybill *et al.*, 2006), the integration of which is necessary to create a more comprehensive understanding (Newell, 1990). Interdisciplinary teamwork is often focused on solving a problem that representatives of one discipline alone would not be equipped to tackle (Irwin *et al.*, 2012), hence it comes with interdependence as well. This is not a weakness but a strength! You can consider your team as a powerful collective brain. Research has shown that well-organized diverse teams often bring forward high-quality end products (Woolley *et al.*, 2015).

▶ **Look out for...**
... disciplinary defaulting. Interdisciplinary teamwork can run into issues when team members are unwilling or unable to work beyond the scope of their own discipline, especially after encountering a clash between their point of view and that of someone with a different background. Attempts at establishing a hierarchy amongst the disciplines involved can destabilize the team even more and make everybody defensive of their approach, effectively ending fruitful collaboration (Derry, 2005).
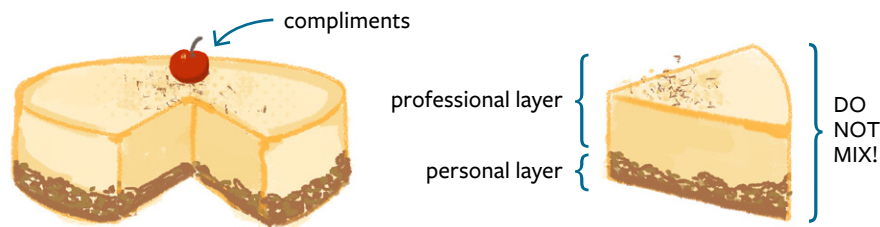
COMMUNICATIVE

Collaboration requires you to be **communicative**. Specifically, you always need to be able to communicate your ideas and your points of view, but also your doubts and questions, to your teammates and often also figures of authority such as supervisors, reviewers and investors. Just as importantly, you need to be able to receive and take up information that others try to convey to you. What sets interdisciplinary teamwork apart is that information is much more likely communicated to you in a way you might not be

used to. To succeed in both, when communicating within an interdisciplinary team, your number one challenge is to create a common language (Van der Lecq, 2016). This means leaving disciplinary jargon behind and keeping in mind the level of understanding your teammates have of your discipline. Vice versa, you can expect and remind your teammates to do the same for you. In short: Don't be shy to ask 'stupid questions' and don't lose your patience when a team member asks 'obvious' questions. Communication between disciplines is littered with potential for misinterpretations. So, if you are unsure about something, keep on asking till you get an answer that helps you.

Be aware that there are different layers of communication. All of the above relates primarily to professional conversations. However, there is also a personal layer to teamwork, and although it should not be overly prominent in professional collaborations, it is beneficial to attend to that layer as well. Well-cared for personal comfort makes a good base to support professional collaboration, as is represented in the cheesecake model here. Hence, if you feel uncomfortable in the team, try to find out how the discomfort comes about and address the issue directly (and in private) with the relevant teammate. Such conversations too easily slip into a defensive or reproachful tone, hence it is good to be cautious. You can set a friendly and respectful tone with your initial approach, signaling: "I am reaching out to you for collaboration, we're in the same boat". Of course, the personal layer also involves individual circumstances. Sometimes, you may experience personal trouble unrelated to the team that keeps you from delivering your part of work as planned. You can do amazing damage control if you let your teammates know as early as possible.In all this, the ground rule is: Do not mix! Everyone involved will have a much more pleasant and smooth collaboration experience if you keep the personal and the professional communication layers clearly separated. And lastly, a cheesecake can technically do without the sprinkles and cherry on top - but boy, do they make a difference! So, go ahead and try out what difference the occasional compliment to your teammates can make...

COMMUNICATION LAYERS

compliments
professional layer
personal layer
DO NOT MIX!

▶   **Look out for...**
     ... getting lost in translation. In an effort to create a common language you can run the risk of losing the specificity or even the essence of a concept. When trying to make disciplinary ideas accessible, remember that communication does not have to be strictly verbal. Visualizing a concept can help you structure your interpretation of it and make it recognizable for other team members.

CREATIVE

When you are *creative*, you draw on many different areas of your experience, knowledge and intelligence. In essence, creativity is the making of novel connections between ideas from different areas – and that is exactly what interdisciplinary thinking needs, especially when in the quest to solve complex issues (Van der Lecq, 2016). Where different views and ideas come together, there needs to be room for new connections, else all you get is stuck. Hence, when you work in interdisciplinary settings, it is a useful routine to loosen up your mind before starting your day. Enjoying some music, fiction, poetry or art can help, or even just flipping through the pages of a children's book.

Creativity is often portrayed as a given; some have it, some don't. Maybe the impression that creativity is a gift echoes from past civilizations: most great cultural traditions, including the Greek, Judaic, Christian, and the Islamic, considered creativity to be divine inspiration - ideas coming from God. This view puts the human in the passive position of a receiver, or transmitter. That is not the idea we want to promote here. Instead, we take creativity to be a skill that can and should be practiced and facilitated, especially in groups.

"Creativity often emanates from groups of people working with complementary skills rather than an inventor toiling as a lone genius"
—   Leonard, 1999

This more contemporary view follows ideas that emerged during the 17th and 18th century, when creativity became increasingly regarded as a fully human capacity that can be actively employed, independent from divine intervention (New World Encyclopedia, 2020). In more recent years, the view of creativity as a skill has been gaining in evidential support and eagerly picked up by companies and other institutions whose thriving depends on their employees' creativity. One of the findings spurring such institutions to re-think their employees' work environment is that creativity can prosper best under particular conditions (Scheffer *et al.*, 2017). Ideal conditions involve an open atmosphere where risk-taking, experimentation, exchange of experience and flow of ideas are actively encouraged. This is just the atmosphere you should find or strive to build in interdisciplinary teamwork.

▶ **Look out for...**

... losing your footing in reality. Creativity should not come at the cost of the practicality, feasibility or applicability of the solution or an unsustainable stretching of disciplinary boundaries. To find a good balance between creativity and pragmatism, you can follow the Disney Strategy below (Elmansy, 2016). This brainstorming method consists of three distinct phases in which you start out with an attitude of "everything is possible", then submit your ideas to a reality-check and finally to a thorough quality control.

DISNEY STRATEGY		
PHASE 1 - **DREAMER**	PHASE 2 - **REALIST**	PHASE 3 - **CRITIC**
▶ Working with fantasies	▶ Setting tangible goals	▶ Critical thinking
▶ Setting up visions	▶ Summarizing resources	▶ Weakness identification
▶ Creative thinking	▶ Setting a time frame	▶ Risk analyses
▶ Positive energy flow	▶ Dividing responsibilities	▶ Alternative solutions
▶ "Everything is possible" attitude	▶ Creating specific action plan	▶ Improving action plan & processes

CRITICAL

Working in an interdisciplinary team, you also need to be *critical*. During your studies, you have probably been trained in what most teachers call 'critical thinking' or 'critical reading', which means to take all information you encounter with a grain of salt and assess its relevance and validity for yourself. However, in interdisciplinary teamwork, you need to be critical not just of others' viewpoints and ideas, but especially of your own. To an extent, of course, this is true of any kind of teamwork. What distinguishes interdisciplinary from monodisciplinary teamwork in this regard is *the extent to which you need to be critical* of possible biases in your own viewpoint.

Consider, for one, the *depth* of the doubt that might arise regarding your contributions to a project. In a monodisciplinary project, what might be questioned is the soundness of your arguments, or the reliability of your sources. These are issues that are usually easily fixed near to the end of a project. In an interdisciplinary project, however, your entire academic framework might be questioned, and with it the values, paradigms and
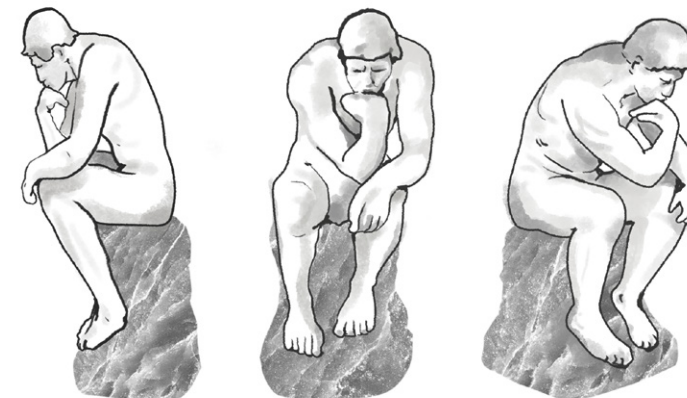
"Le Penseur" (1881) from Auguste Rodin. In interdisciplinary work, critical thinking entails taking different perspectives and being aware of their ontological and epistemological assumptions. This always goes hand in hand with ethical reflection.

assumptions underlying any contributions you make from within your disciplinary perspective. This is evidently a different level of doubt, reaching into the roots of your beliefs and what you think you know. More likely than not, in the course of debating your different disciplinary findings as a team, you will find yourselves bumping into questions of philosophical quality. For instance, you may have to re-think your relationship to evidence (such as: what counts as evidence? What role do subjectivity and objectivity play?), your ways of obtaining data (qualitative / quantitative? And is there a clear line between the two?) and establishing knowledge or theories (empirical / theoretical?; Experiential / experimental?; Descriptive / normative;? What role does morality play?). In other words, interdisciplinary critical thinking is never far from epistemology, metaphysics and ethics.

Besides its depth, another characteristic that distinguishes interdisciplinary critical thinking is the *degree* to which you need to actively apply it to your own work. Although, as mentioned before, a self-critical standpoint is certainly called for in any academic activity, the feedback and review dynamic is a different one in multidisciplinary teams: you might be the lone representative of your discipline and accordingly responsible for your own quality-checks to a wider extent than in a monodisciplinary team, where colleagues keep each other in check. As your multidisciplinary teammates do not share your expertise, they cannot point you to your technical or methodological mistakes, gaps in your literature search and the like. Consequently, in an interdisciplinary project you need to exercise a more thorough and encompassing self-critical approach than usual.

▶ **Look out for...**

... being aggressive and becoming defensive. It is easy to fall into a defensive mode if you feel like your contribution is being unjustly attacked. Remember that each one of the collaborators you are working with has a different background, method or objective than you might be used to. Take that into account when receiving criticism. Even so, if you truly stand behind something, do try and convince your critic – but do it by improving your argument, instead of shouting louder.

"We cannot solve our problems with the same thinking we used when we created them."
— *Albert Einstein*

Interdisciplinary teamwork requires you to be **flexible** in your thinking. No researcher walks in and out of an interdisciplinary project with the same views and ideas - which would mean a failure of the project (and of the researcher). The step of integrating different disciplinary views is necessarily a transforming one, which is why it so often stirs conflicts and reluctance amongst experts. In these moments especially, you need to be able to get over your pride and open up to the possibility of changing your view and, consequently, your mind. You can regard this as mental gymnastics; flexibility is the clue!

...And just like in gymnastics, you can only progress by recognizing your boundaries and actively trying to stretch them. In interdisciplinary teamwork, it is usually when you are most reluctant to change your view that you can notice reaching your boundaries. This can be unpleasant for everyone, as it blocks the team from progressing. But don't worry, it's normal to struggle with too much change at once! In such situations, it helps to realize that if you get defensive, this means that you need space. Hence, if you notice you're tensing up, grant yourself to take a breath and shake it out. When you feel relaxed again and ready to take in new thoughts, return to the topic of controversy and ask for support. If you communicate your difficulties, your teammates can help you to look at your own work with fresh eyes. Listen to their ideas, questions and doubts and re-evaluate yours in light of your teammates' views. Others will be critical of your contribution and while you should feel comfortable defending it, you may also identify some biases or blind spots of yours. Most often, these are already woven into the fabric of your disciplinary grounding and, embedded within your disciplinary field, you would hardly have noticed them. Giving way to your teammates' ideas and making appropriate adjustments does in no way weaken your arguments, rather it allows you to *eliminate* weak points from your reasoning, thus strengthening it.
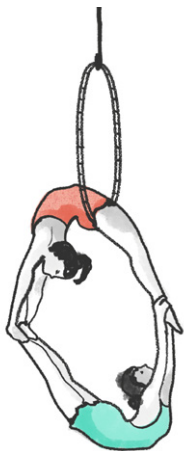
Here is a possible way to get out of a dead end when you find yourself in head-to-head collision with a different disciplinary view. Ask yourself, hypothetically:
- Is there any way in which I could be wrong?
- Is there any way in which my team mate could be right?

Four
No
Three

Ridgley, no date

bryanridgley.com
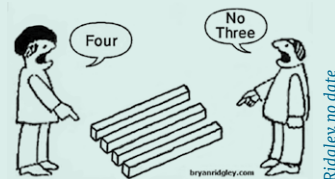
If you can even as much as *imagine* a way in which either or both of these could be the case, you are already a little more flexible in your thinking. The next step is to try and move on from *being part of the conflict* to *analyzing the conflict* and your part in it. Working together that way, you can step up your game by understanding not only each other's views, but also why they are different.

Your strength lies in knowing where you're coming from and using that knowledge to upgrade your level of understanding and convince your teammates.

CONFIDENT IN YOUR COMPETENCE

To be a successful contributor to interdisciplinary projects requires you to feel **confident in your own competence** (Augsburg, 2017). It is crucial that you can articulate the knowledge and skills you have learned during your studies and convince others of its importance.

The qualities discussed on the previous pages have stressed the value of openness to other people's way of thinking, but the same counts for others' openness to your way of thinking. Concretely, this means you will need to stand up for what you have to say and sometimes walk the extra mile to convince your teammates of your competence and the relevance of your discipline's insights. To encounter skepticism is a natural part of your professional interaction in an interdisciplinary setting. Just consider that most likely, none of your teammates understand enough of your discipline to accurately evaluate your competence based on the content of your contributions. They can only judge based on *the way you make* your contributions. That is where your competence and your confidence in it will be key.

It may seem hard to remain confident when not only your competence, but also your entire intellectual framework is under scrutiny. However, you can train your confidence by getting to know your own and your discipline's competencies and appreciating them. Here, your personal and academic development overlap, as self-reflection mingles with meta-reflection on your disciplinary perspective (read more on self-reflection, metacognition and perspective-taking in the following section on "Skills & Attitudes"). In cases of overwhelming intellectual conflict, uncertainty or strong doubt, remember that questions about your disciplinary framework do not need to shake your foundations. Rather, such questions can serve you to notice and acknowledge your foundations, to include them in the picture and make use of them as important context. In this regard, as an interdisciplinary researcher, you need to work much the way that modern anthropologists do: they put their understanding of whatever phenomenon they study in context of their own culture. This does not devalue their understanding of the phenomenon, nor does it threaten their own cultural framework. On the contrary, it enriches both by clarifying the relationship between them. The same way, you will come to understand the interdisciplinary problem and your own discipline's world views significantly better if you know your own competencies and make them part of the picture you see.

...confusing confidence with stubbornness or arrogance. Being confident also means not to be afraid to admit and learn from errors (see "growth mindset" in the introduction to the present section). Plus, you can deliver an argument or present an idea all the more convincingly if you show that you have also thought about its limitations and weak points and do not hesitate to address them. Whether you are generally more in need of building your confidence, or of learning to question yourself is a matter of self-knowledge and worth finding out!

CURAGEOUS

Interdisciplinary work requires a willingness to take risks. The unpaved roads across and between fields can be hazardous, so if you want to work in an interdisciplinary project, you need to be courageous enough to venture into remote areas of thought, go off the beaten tracks and make new paths of your own (Augsburg, 2017). More often than not, interdisciplinary answers or solutions are controversial in the eyes of disciplinary experts, so there is a good chance you will find yourselves stirring up things more than usual and in more than just one field of expertise. Because of this, and because of the still prevailing skeptical attitude towards interdisciplinary work, reviewers will quite certainly scrutinize your interdisciplinary work more rigorously than the more conventional mono-disciplinary works. Even though this may sometimes feel rough and you are more likely to experience failures in the course of your interdisciplinary adventures, don't let them discourage you – let them teach you and grow stronger through it! That way, they will become some of the most valuable experiences in the long run.

To brace yourself for any adventure that lies ahead, it helps to mentally go through some of the concrete risks you may have to accept when you decide to take part in interdisciplinary research. Besides harsh criticism or rejection from experts, you also need to be willing to risk not reaching a satisfying or publishable result at all. This can happen more easily in interdisciplinary than in monodisciplinary projects because there are less
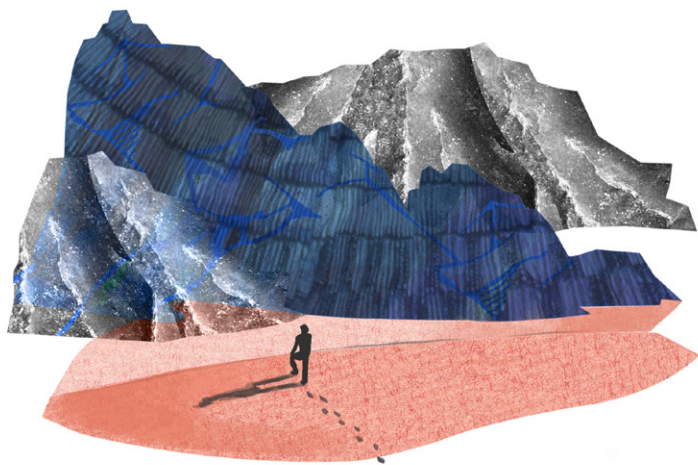
Interdisciplinary research takes you off the beaten tracks.

"Only those who will risk going too far can possibly find out how far one can go."
— *T.S. Eliot (1931)*

established and useful methods available for approaching interdisciplinary problems. Hence, you may have to draw up your own methodology and such premieres are prone to failure. In that case, it can be worth taking a baby-steps approach, for instance by conducting pilot studies to test your methodology or by submitting your methodology for peer review before applying it.

Last, but not least, you need to be aware that when doing interdisciplinary work, you are challenged to think outside all boxes – and that includes your own box. That is to say, if you have previously published ideas on a topic relevant to the interdisciplinary project you are about to join, you may come to look at them from a different angle and discover that you do not agree with yourself anymore. In that case you may need to contradict, relativize or modify your own previous stance. However, that is nothing to be ashamed of, but in fact an achievement you can wear with pride. It proves your ability to think critically and outgrow yourself.

▶ **Look out for...**

...overdoing the "dreamer" phase of the Disney strategy (see more on this in the section "creative"). Risk needs to be balanced with care and planning; hence, the more adventurous you are in the dreamer phase, the more thorough you need to be in the realist and critic phase. Remember that you carry responsibilities as a member of the research community, and that you will probably work with other people's money, hence any risks you intend to take need to be well-considered. Do not hesitate to seek help for conducting a thorough risk-assessment.

COMMITTED

An interdisciplinary team demands more commitment from you than a regular team, because you are irreplaceable. None of your teammates can take on your share of work for you, since you alone are responsible for representing your discipline.

This being said, interdisciplinary teamwork also tends to bring out a strong sense of commitment in researchers because it is exploratory by nature and therefore often fosters an atmosphere of excitement. However, not everyone gets excited enough about interdisciplinary work to be able to keep up with its high demands. That is fair enough but seeing that you are irreplaceable and hence there is no option to back out half-way, you need to find out beforehand whether you can fully commit to sticking through the project with your team. A good approach is to start out by forming a clear idea of the required time and energy investment before you make any promises. Make sure you and the rest of the team are on the same page concerning your investments. In this respect, be aware that time investment is often larger than in teams in which only members of the same discipline are present.
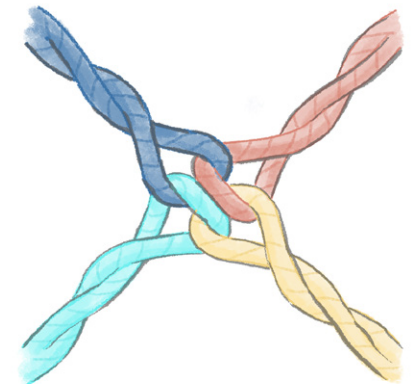
Besides such considerations of time and energy investment, interdisciplinary team-work also demands commitment on the level of mindset. This is important because it means that you are not simply striving to reach the goal of answering your question; you are striving to do justice to all the relevant disciplinary perspectives and to optimize the process of integration.

As a consequence of such commitment, you may have to abandon some too-easy answers when they turn out to be short-sighted, or you may find out that your question was wrong or needs refining, that your approach needs revision, that you have not included all necessary disciplines, that a newly devised methodology needs to be tested and improved before you can move on, etc. All these options are also a form of interdisciplinary success, in that they reflect your commitment towards the interdisciplinary way of thinking and working.

▶ **Look out for…**
…holding on to a fixed idea: sometimes letting go is a sign of commitment to the interdisciplinary open-angle attitude. In other words, commitment does not equal rigidity. In an article concerned with the efforts it takes to kick off and push through with interdisciplinary projects (Long, 2001), the author also addresses the necessity of letting go of fruitless endeavors and humorously points to the proverb: "Don't try to teach a pig to sing, you will frustrate yourself and annoy the pig."

…AND UNDERLYING ALL THIS: EMPATHY

Empathy, the ability to cultivate awareness of and immersion into the perspectives of others, helps you make connections and allows you to reflect on your own values and assumptions. This is a door-opener when working in interdisciplinary settings. Most of the qualities introduced in the present section either require, benefit from or exercise empathy. In Table 3 are examples of how empathy plays into each of the qualities we have discussed.

Table 3. Role of empathy in academic qualities

QUALITY	INVOLVEMENT/EFFECT OF EMPATHY
CURIOSITY	Empathy drives curiosity: an awareness and appreciation of the unknown or the 'other' (person, experience, phenomenon, discipline, outlook…) fosters authentic curiosity.
COLLABORATION	Empathy helps you to let go of / avoid forming assumptions that would hinder collaboration. It increases your sensitivity to different ways of working, but also towards different audiences, different cultures, educational backgrounds, etc. This increases your ability to present information in an accessible way to your team members, and later to a wider audience.
COMMUNICATION	Empathy opens the floor for unrestrained discussion: it helps everyone feel respected and comfortable to speak and ask freely, thus allowing for a better and freer information flow. For instance, being empathic to others' lack of understanding helps you remember that there are no "dumb questions".

CREATIVITY	Putting yourself into other people's shoes allows you to draw inspiration from beyond your own repertoire (of disciplinary background, culture, past history, way of thinking…). Creativity sparks and flows best when you're in connection with your teammates and the sources you work with.
CRITICISM	Empathy prevents taking (or giving) criticism personally: it helps you to understand where criticism comes from and hence to see past triggered emotions. Reversely, it helps you to formulate criticism in a way that avoids emotional triggers for others.
FLEXIBILITY	Extending empathy towards yourself gives you space when you notice you're at the limits of your flexibility. Acknowledging your boundaries often has the effect that you find yourself able to stretch further, or to reinspect and realign, then re-enter the discussion. Empathy also allows you to do the same for others: Notice when a little break from the discussion or a change in tone or perspective is required, so you can make space where it is needed.
CONFIDENCE IN COMPETENCE	Empathy towards yourself prevents you from applying criticism that is directed to your discipline's insights to your own personal worth instead. Your discipline does not equal your personal identity. When you feel your foundations wobble due to doubts or conflicts, an empathetic lens reminds you that such conflicts are not personal but intellectual and provide you with an opportunity for curious reflection.
COURAGE	When you face a tough decision, harsh criticism or failure, or when you enter unknown territory, it is okay to be scared. Courage is not the absence of fear, it is the strength to overcome it. Empathy enables you to acknowledge and accept your fears, and to do the same for others. This helps you to clear your mind, seek support, brace yourselves and keep going in unison.
COMMITMENT	Empathy supports you in keeping motivated and living up to your promises. Sometimes, we all get a little tired, overwhelmed or fed up. In such moments, it helps to feel your teammates' enthusiasm as if it was your own, oar to notice that they are struggling equally, and to want to keep it together for them. Conversely, it is easier to ask your teammates for help when needed if you feel their empathy, too. This can avoid the worse struggle of having to admit that you failed to uphold your side of the bargain when it's too late to fix the issue.

UP TO YOU
Alan Alda's podcast "Clear & Vivid – Conversations About Connecting and Communicating" has empathy as a recurrent theme. In acknowledgment of its importance, the podcast features an entire episode on empathy, drawing from all other episodes that have implicitly or explicitly engaged with the topic. Empathy is discussed from many different angles and its involvement in many other skills and professions is nicely illustrated. You can find the episode here:
www.stitcher.com/show/clear-vivid-with-alan-alda/episode/empathy-what-good-is-it-anyway-60670355

Enrich yourself – skills & tools
you will take home from interdisciplinary teamwork

The last section was all about elemental qualities that support interdisciplinary teamwork. This section is all about some more abstract skills and attitudes that you will take from interdisciplinary teamwork. Consider these as some of the most lasting benefits for your own development that come with interdisciplinarity collaboration, since they are ways of thinking and working that will make you a desirable employee, a good conversation partner, a critical reviewer, and a broad as well as a sharp analytical thinker.

HARD TO GET THERE – WORTH THE EFFORT
"Is it hard?"
"Not if you have the right attitudes. It's having the right attitudes that's hard."
(Pirsig, 1974)

This quote is one to remember, especially throughout your first interdisciplinary experiences. Indeed, the skills and attitudes mentioned hereafter are not at all easy to master. However, they are worth their effort: you will find a lot of things easier in life if you manage to adopt even some of these skills and attitudes. Hence, don't let the difficulties of training them discourage or hinder you in your development.

Interdisciplinary teamwork trains you in some skills and attitudes that emerge with practice and experience. You can think of them as the free special gadgets in your skills toolkit that come with the interdisciplinarity package. The ones we address are systems thinking, disciplinary humility, reflection, bird's eye view or enlarged perspective and self-authorship. The following paragraphs will take you through the definitions and implications of these skills and attitudes and discuss their role in interdisciplinary work.

SYSTEMS THINKING

Systems thinking describes the ability to analyze connections within and between concepts. This entails awareness of the fact that a change in one part of the system has consequences for all other parts of the system. Diluting the borders between disciplines and looking at systems as a whole can clarify connections between elements that contribute to the bigger picture (Boulding, 1956). Systems thinking is a powerful tool that will help you structure your interdisciplinary thoughts and create a common language with your team.

SYSTEMS THINKING AS INTERDISCIPLINARY METHODOLOGY
In the present section, systems thinking is addressed as a competency. If you want to know more about how systems thinking functions as a tool, you can check out the section on interdisciplinary methodology in part I of this booklet (in case you haven't done so already).

Enlarged perspective
To be able to consider a system in its entirety you often need to broaden your perspective. Try beginning with exploring disciplines that have a lot of overlap with your own and challenge yourself with including a discipline of an entirely different field.

Synthesis & integration
To retain an overview of the system, it is necessary to synthesize and integrate the information within it.

Tolerance for ambiguity
When thinking in systems that encompass multiple disciplines it is not unlikely that you will encounter some ambiguity with regards to definitions of certain concepts. While you can attempt to continue synthesizing and integrating, in certain circumstances ambiguity has to be accepted.

Metacognition
As an interdisciplinary thinker, you need to be aware of your own cognitive processes and what influences them. This thinking about thinking is called metacognition (Flavell, 1979). When working in an interdisciplinary context, you often switch between subjectivity and objectivity. Being aware of your subjective viewpoint will help you identify areas of your own discipline that have potential to become part of an interdisciplinary effort. Objectivity is useful to regard your contribution from a distance and determine whether it is indeed appropriate. Flexibility in moving between the two is crucial. In addition, you will need to switch between reductionist & analytic versus synthetic & holistic thinking, and between disciplinary perspectives on complex problems.

Using systems thinking and systems mapping is thought to promote at least four skills appropriate to interdisciplinary learning and research (Repko and Szostak, 2021). These skills are: perspective taking, nonlinear thinking, holistic thinking and critical thinking.

DISCIPLINARY HUMILITY

As discussed in the section on interdisciplinary learning goals, disciplinary grounding in a specific "home" discipline is important as it provides you with a template to compare the new information from other disciplinary perspectives to. However, you should be prepared to recognize not only the strengths, but also the weaknesses of said disciplines including your own, and acknowledge their limitations . Such disciplinary humility is not only part of interdisciplinary work but will also open your mind in many other contexts of your life and help you listen more openly and eagerly to what others have to say – even and especially when it does not intuitively suit your world view.

The figure below by Tripp & Shortlidge (2019) illustrates the central role of disciplinary humility as a vital mediator, ensuring that intellectual activities and competences lead up to interdisciplinary understanding.
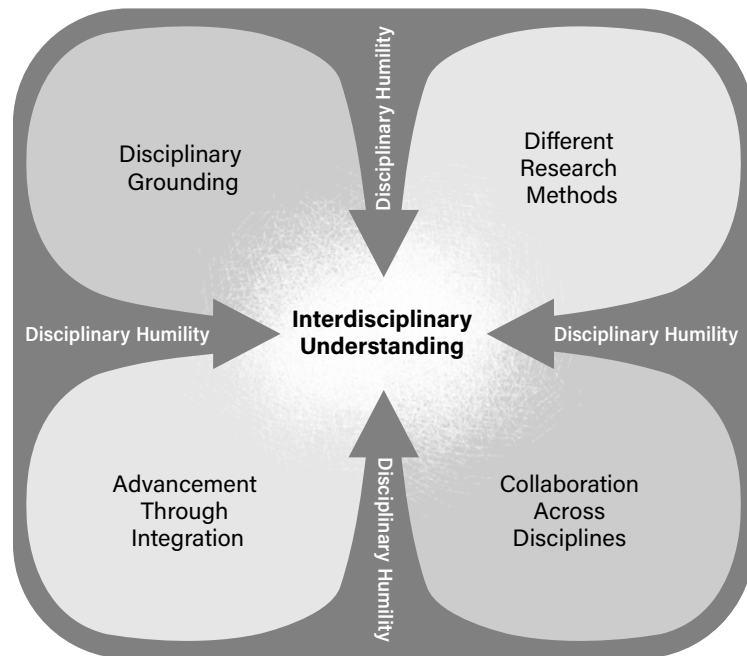
In its role as an enabler of interdisciplinary achievements, disciplinary humility contributes to your critical thinking in the following ways:

Demythologization of experts

While disciplinary expertise does have its value, it should not be regarded as the holy grail of academia. Issues that are currently relevant cannot be solved in isolation but require networks in which relevant communication from other disciplines can be caught, integrated and used to advance knowledge across fields (Boulding, 1958).

Sensitivity to bias

Part of developing disciplinary humility is becoming aware of and recognizing your own and other's ignorance and biases (Derry, 2005). During interdisciplinary work it is not only relevant to identify possible biases you may hold, but it also has to be called out and rectified. This will move the effort of systems thinking, synthetization and integration forward.

REFLECTION

Reflection is an invaluable tool to become more aware of your own cognition and increase your sensitivity to bias. Reflection can take on a number of different forms. You might be asked to write a reflection paper in which you lay out your own perception of various disciplines and how your perception might influence your work with them. However, reflection can also be much smaller and situation dependent. You might have received some criticism you felt yourself reacting to in a way you did not expect. Reflection on such circumstances can prepare you to act more self-aware and offer you and others more insight into which disciplinary elements you identify with. The relationship between you and the work that you are doing also becomes more clear-cut.
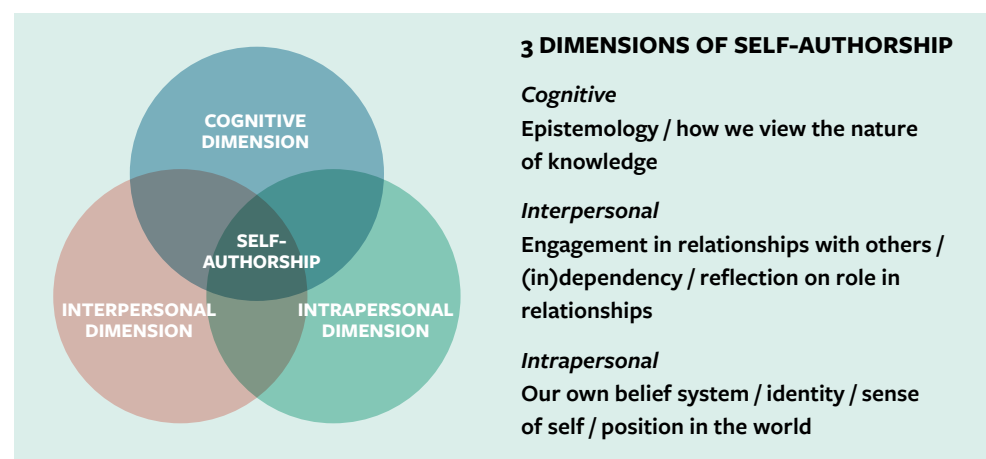
Note that if you reflect on your progress in writing and in a systematic and periodic fashion, you give yourself the chance to identify patterns in your thinking / approaches / behaviors, such as recurring biases or flaws. To help you identify such patterns, you could get in the habit of dedicating part of your reflection to your weak points or possible failures in particular (e.g. by giving yourself advice on what to do next time). This may not sound tempting, but if you try it, you may find that frustration fades once you have put it on paper – plus, you will probably thank yourself later when re-reading your notes helps you escape your vicious cycles.

SELF-AUTHORSHIP

Curious people challenge their views of self, others and the world, which "appears to be a pathway to the continual building of meaning in life", as Kashdan and Steger (2007) put it. This sounds very abstract, but in fact it is something very practical that we all do continuously. We put things together in a way that makes sense to us. When we think about how we make sense of the world and actively take charge in doing so, this process is the basis to self-authorship. This is also a process integral to interdisciplinary work,

hence interdisciplinary experience will also help you develop a sense of self-authorship (Van der Lecq, 2016).

Baxter Magolda provides you with a clearly stated definition of self-authorship: "Self-authorship is the capacity to internally define a coherent belief system and identity that coordinates engagement in mutual relations with the larger world" (Baxter Magolda & King, 2004, p. xxii). Below, you can find the concept visualized in the form of a Venn diagram showing it as the intersection of three aspects of development, which are briefly described in the adjacent information box.

3 DIMENSIONS OF SELF-AUTHORSHIP

Cognitive
Epistemology / how we view the nature of knowledge

Interpersonal
Engagement in relationships with others / (in)dependency / reflection on role in relationships

Intrapersonal
Our own belief system / identity / sense of self / position in the world

As you can see in the above model, the three main elements of self-authorship are cognitive maturity (cognitive dimension), an integrated identity (intrapersonal dimension) and mature relationships (interpersonal dimension). You can achieve these in an interdisciplinary context because you are more directly confronted with views that differ from your own and need to decide when to defend and when to adjust your approach. Continuously reflecting on the dialogue you enter with collaborators will help you determine your position in relation to others, in relation to the world at large, and will thereby also help you develop a stronger sense of identity.

Many interdisciplinary scenarios in which you will find yourself during your studies are designed to provide a balance between guidance and empowerment. Working within this balance also promotes self-authorship by giving you enough freedom to determine your path.

UP TO YOU
Think about your experience with self-authorship. When did you last make a conscious decision about your (academic) path? What are important factors that influence your decisions? Do you feel confident in your agency when it comes to shaping your future, as well as your present intellectual, professional and/or personal development? If not, what is holding you back?

Be aware of your qualities

Boosting your CV

Most 21st century jobs require an openness to learning from and with others, more than perfect mastery of a particular skill (AAC&U, 2002). Hence, employers are interested in hiring interdisciplinary students for their qualities. Below is a list of some qualities which you can mention to sell yourself; after completing some interdisciplinary training or gathering experience in interdisciplinary work, you have support for adding the abilities and traits hereunder to your CV or add them as "skills" to your LinkedIn profile.

▶ thinking conceptually
▶ identifying and solving problems
▶ understanding other value systems
▶ evaluating alternatives
▶ deciding on a course of action
▶ changing one's opinion in the light of (new) facts
▶ effective written communication skills
▶ effective oral communication skills
▶ effective and extensive teamwork experience
▶ ethical sensitivity
▶ constructive responses to criticism

These are just some examples. All the aforementioned qualities and behaviors, skills and attitudes can also be added to the list! It is worth making a checklist for yourself and reflecting on your development. It is also important once in a while to stop and look back on your thoughts and behaviors, and to acknowledge and celebrate when you have mastered a new skill or attitude. If you find it hard to evaluate for yourself, you can ask co-workers, teachers, peers or friends for feedback.

UP TO YOU
Go through your CV and (if you have one) your LinkedIn profile. Do you have a skills section? Are there some skills already noted down that will help you in interdisciplinary teamwork and if so, how will they help? Are there skills mentioned on the previous pages that you think already have and could add to your CV?

PART III
INTERDISCIPLINARY PRACTICE
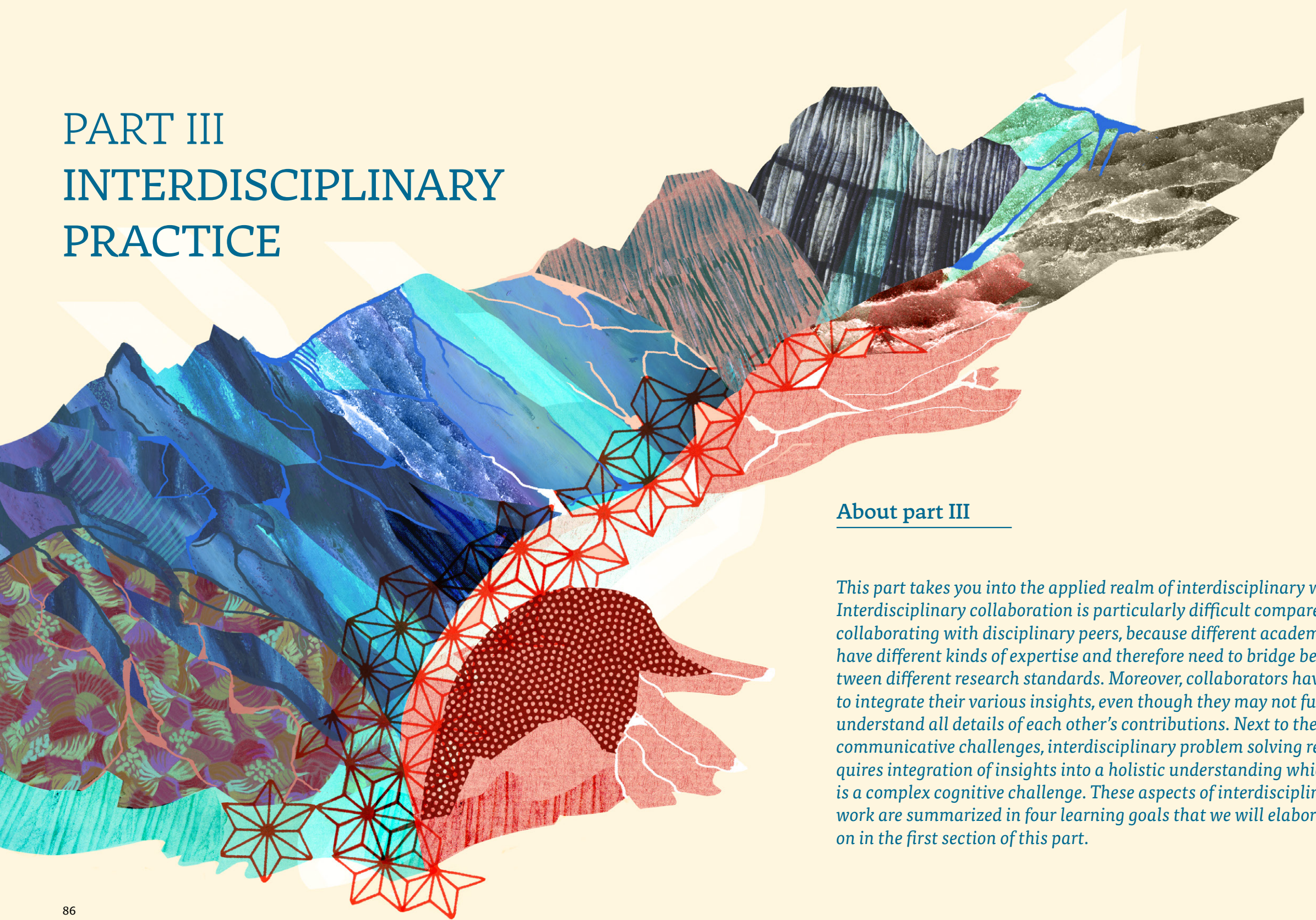
About part III

This part takes you into the applied realm of interdisciplinary work. Interdisciplinary collaboration is particularly difficult compared to collaborating with disciplinary peers, because different academics have different kinds of expertise and therefore need to bridge between different research standards. Moreover, collaborators have to integrate their various insights, even though they may not fully understand all details of each other's contributions. Next to these communicative challenges, interdisciplinary problem solving requires integration of insights into a holistic understanding which is a complex cognitive challenge. These aspects of interdisciplinary work are summarized in four learning goals that we will elaborate on in the first section of this part.

PART III
INTERDISCIPLINARY
PRACTICE

After introducing these learning goals, it might be interesting to look at them from an educational perspective. To that purpose, we will add exemplary grading rubrics you can examine to see for yourself what interdisciplinary competencies might be assessed by supervisors and how they are scored. Getting a better idea on how interdisciplinary competencies are evaluated will help you in future interdisciplinary assignments.

> **UP TO YOU**
> Why not try and assess your own work in case you decide to tackle some of the suggested exercises you can find in the last section of this booklet, under the heading "Exercises to get you started in practice" …?

To close off this part about interdisciplinary practice with some real-life practical insights, we will address the challenges of interdisciplinary collaboration in more detail by passing on to you some of the wisdom that comes from the experiences of researchers in interdisciplinary fields. These researchers were interviewed to share their thoughts on questions like: What challenges did you encounter in interdisciplinary teamwork? What skills and attitudes were really important during the interdisciplinary process? What did you learn from interdisciplinary collaboration? etc.

Last, but not least, we will leave you with a pool of resources to satisfy your curiosity and inspire you on your further path. These will entail more literature to consult on the topic of interdisciplinary research and education, but also a set of interdisciplinary works you can read to expand your knowledge, to observe how other authors have handled the challenge of integrating various disciplinary perspectives, and of course also simply to enjoy the enthusiasm and brilliance of some of these interdisciplinary authors.

You in an interdisciplinary team

LEARNING GOALS

The following four learning goals are considered essential in the field of interdisciplinary education and clearly reflect the methodological process of interdisciplinary research (see section on "Repko's steps"):

- ▶ Disciplinary grounding
- ▶ Perspective taking
- ▶ Discovering common ground
- ▶ Integrating perspectives

The idea is that once met, these learning goals facilitate collaboration in a multidisciplinary team, support the integration of different disciplinary perspectives, achieve a more comprehensive understanding of complex problems and/or achieve interdisciplinary solutions to solve these problems. Let us have a closer look at each of them in turn.

1. *Disciplinary grounding*
Grounding involves having a basic knowledge and understanding of the involved disciplines, especially of your own discipline, as well as ways in which their knowledge is constructed, validated and communicated.
This implies:
- ▶ *Knowing which phenomena* are being studied in the disciplines (basic disciplinary concepts, theories, assumptions)
- ▶ *Understanding the basic assumptions* of these disciplines (for example assumptions about the rationality of human beings), the epistemology (the way of testing any belief or assertion of truth), its methods and ways of validation, and genres of communication (e.g. a historical narrative, a law, a research paper)
- ▶ *Assessing which disciplines might best inform the particular question* or issue, and what aspect of each of these disciplines are used (e.g. particular concepts, methods or forms of communication)

2. Perspective-taking

This learning goal involves analyzing the problem from the position of each interested discipline and identifying their commonalities and differences. It also encompasses an attitude of open mindedness to- and valuing of different perspectives, and the willingness to reflect on one's own biases and assumptions. This includes:

▶ *Appreciating different (personal and disciplinary) perspectives*, and becoming aware of one's own biases and assumptions
▶ *Framing a (research) question* that justifies an interdisciplinary approach;
▶ *Considering the object of study from more than one disciplinary perspective* and using sources from two or more disciplines
▶ *Evaluating and addressing the limitations* and the value of the disciplinary perspectives

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COGNITIVE DECENTERING

Perspective-taking also hangs together with a skill called "cognitive decentering". That term denotes "the intellectual capacity to move beyond a single center or focus (especially the innate tendencies towards egocentrism and ethnocentrism) and consider a variety of other perspectives in a coordinated way to perceive reality more accurately, process information more systematically, and solve problems more effectively" (Hursh *et al.*, 1998, p. 37). This skill is particularly crucial to have stimulating and purposeful discussions between disciplines.

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3. Discovering common ground

Common ground is usually defined as the shared basis between conflicting disciplinary insights or theories. To identify common ground is a creative process that involves modifying or reinterpreting disciplinary elements that conflict. Assumptions from two or more disciplines are made explicit and are compared, and some degree of overlap between disciplinary perspectives are identified. It also incorporates the identification of how terms are used differently in different disciplines and defining problems explicitly in neutral terms in order to create a common vocabulary that can be applied to the object of study.

4. Integrating perspectives

This learning goal involves the final step, integration, generating a new understanding that would not have been possible using a single discipline. It includes being able to use integration techniques (e.g. models, metaphors) to find new holistic understanding. Integrating perspectives is a creative process, and can take many forms, such as developing a new model, a metaphor, a method, or a future scenario. The new metaphor, interpretation, or model is also tested or used to solve a problem or guide research, and to communicate clearly. Integrating perspectives often also requires having confidence and intellectual courage (out-of-the-box thinking).

Below, a general rubric for interdisciplinary education is described, which is the result of the combination of several rubrics which have been used in some programs at Utrecht University. The rubric includes seven categories which are considered as the most important for interdisciplinary learning:

1. Disciplinary grounding
2. Perspective taking
3. Common ground & Integration
4. Critical Reflection
5. Collaboration
6. Communication
7. Adaptability and creativity

The first three are typical learning goals in interdisciplinary learning, while the last four are competencies or general academic skills that are vital for interdisciplinary work.

The rubric can be used by students as well as by teachers to self-evaluate or to assess interdisciplinary competencies regardless of the 'product' of the learning activity. Which of the seven categories are used for assessing an assignment or learning activity, depend on the main learning objectives of the assignment. The weight of the used categories does also depend on the learning objectives of the specific assignment used in a course.

First, we describe the seven general interdisciplinary categories (Table 4). Next, these categories are transformed into a rubric (Table 5), and lastly, we provide two example rubrics for specific assignments: an oral assignment ('the fictitious dialogue') and a writing assignment for an interdisciplinary paper.

Table 4. Seven interdisciplinary categories

CATEGORIES	DESCRIPTION	ASSESSMENT CRITERIA
1. **DISCIPLINARY GROUNDING**	Disciplinary grounding involves having a basic knowledge and understanding of the involved disciplines as well as ways in which their knowledge is constructed, validated and communicated. This implies knowing which phenomena are being studied in the disciplines (basic disciplinary concepts, theories, assumptions), understanding the basic assumptions of these disciplines, the epistemology, its methods and ways of validation, and genres of communication (e.g. a research paper, a review, a law, a historical narrative).	▷ Justification of the need for an interdisciplinary approach. ▷ Justification of the choice of contributing disciplines: which disciplines are relevant regarding the problem, which are chosen to be used, and which are left out, and why? ▷ Critical overview of the 'state of art' of the relevant disciplines regarding the problem. ▷ Insights are presented in a coherent way and relevant terms are explained.
2. **PERSPECTIVE TAKING**	Perspective taking involves analyzing the problem from the position of each interested discipline and identifying their commonalities and differences. It also encompasses an attitude of disciplinary humility and open mindedness to- and valuing of different perspectives, and the willingness to reflect on one's own biases and assumptions	▷ Open mindedness: appreciation of and genuine interest in different (personal and disciplinary) perspectives; ▷ Disciplinary humility: awareness of his / her own biases and assumptions and of the limitations of his/her own discipline. ▷ Valuing other (non-) disciplinary perspectives as a part in the problem-solving process.
3. **COMMON GROUND & INTEGRATION**	**Common ground** is the shared basis between conflicting disciplinary insights or theories. This is a creative process that involves modifying or reinterpreting disciplinary elements that conflict. It also incorporates the identification of how terms are used differently in different disciplines and defining problems explicitly in neutral terms. **Integrating perspectives** involves generating a new understanding that would not have been possible using a single discipline. It includes being able to use integration techniques (e.g. models, metaphors) to find new holistic understanding.	▷ Clear and critical analysis of (methodological and theoretical) strengths and weaknesses of each disciplinary insight; ▷ Clear analysis of similarities and differences between disciplinary insights related to the research question(s). ▷ Common ground has been found. ▷ Key concepts are defined in neutral terms. ▷ Disciplinary insights are integrated into a new understanding of the problem to answer the research question.
4. **CRITICAL REFLECTION**	Reflection is a purposeful activity in which experiences are analyzed, in order to learn and improve. Evaluating an interdisciplinary project and its value and difficulties makes students aware of the intricacies of interdisciplinary work, and considering how to do it better next time helps consolidate the learning experience. A broader awareness is reflected in how the proposed solution may impact society (who/what will be affected in terms of e.g. health, politics, economics, social structures, etc.). In addition, the potential limitations of the proposed solution are addressed.	▷ The reflection provides valuable insight in the phases of the process, the challenges faced, and the learning gain. ▷ The reflection shows implications for future learning. ▷ The reflection addresses a broader awareness by explaining the impact of the proposed solution and by addressing its potential limitations (and possibly strategies to overcome these limitations).
5. **COLLABORATION**	Interdisciplinary collaboration requires more of students' collaboration skills than disciplinary teamwork does. First, the need to explain and discuss perspectives to each other clearly and build on each other's ideas is more challenging in interdisciplinary teamwork for students than when collaborating with peers from the same discipline, where they speak the same language and do not need to explain and discuss everything extensively. Due to the lack of experience students have in each other's disciplines where it is not always possible to critically examine the works of others, they also need to learn to trust and respect one another. Team and task regulation is needed in all teamwork, although in interdisciplinary collaboration there is more effort from students because they need each other's contributions and feedback in all parts of the project and are not able to divide tasks as they normally do. Further, the complexity of interdisciplinary projects requires compromising in order to keep the project manageable.	▷ Listening with an open mind to other personal and/or disciplinary perspectives; ▷ Explaining in layman's words of one's own disciplinary perspective; ▷ Trusting and respecting the expertise of team-members; ▷ Providing constructive feedback and shows openness to feedback from others; ▷ Clearly exchanging goals, priorities and values, and making concessions to formulate a common goal; ▷ Awareness of and sensitivity towards the position of other team members and see how disagreements can occur before they do.
6. **COMMUNICATION**	Communication in interdisciplinary teamwork includes being open minded and non-judgmental in listening to and trying to understand others' perspectives. Explaining clearly is important as peers from other disciplines do not share the same background as is the awareness of the diversity of disciplinary language, differences in understandings of concepts and terms	▷ Is aware of the level of knowledge of the audience he/she is addressing. Can patiently explain disciplinary knowledge to others without using disciplinary jargon. ▷ Listens to others, is open minded and non-judgmental. ▷ Is able to effectively communicate his/her findings regardless of the medium used (writing, oral presentation, etc.)
7. **ADAPTABILITY & CREATIVITY**	Interdisciplinary work is creative and innovative, with unknown outcomes and a risk of failure. Thus, in disciplinary education, students have to cope with the fact that teachers do not have all the answers. This requires a tolerance for ambiguity, the courage to venture in unfamiliar space, to grapple with periods of insecurity, and to make mistakes.	▷ Thinks creatively in situations that are unfamiliar and doesn't give up easily. ▷ Thinks out of the box and takes risks because he/she realizes risk aversion stands in the way of originality. ▷ Sees challenges as an opportunity to develop and, if mistakes are made, sees them as a learning opportunity. ▷ Is aware that interdisciplinary problems often do not have a right or wrong answer and that more solutions are possible.

Table 5. Rubric interdisciplinary competencies

CATEGORIES	INSUFFICIENT (NOVICE)	SUFFICIENT-GOOD (INTERMEDIATE)	GOOD-EXCELLENT (MASTERY)
1. DISCIPLINARY GROUNDING	▷ The complexity of the problem is not well indicated and the need for an interdisciplinary approach is not justified. ▷ Key disciplinary insights are described too superficially, and/or some key concepts are missing. ▷ The selection of one or more disciplines is questionable and/or important disciplines related to the problem are lacking. ▷ Insights are not presented in a coherent and balanced way, and definitions on key concepts are missing.	▷ The problem is well introduced, but the relevance could be more elaborate. ▷ It is explained why the involved disciplines are required, and why others are left out. ▷ Nice elaboration on some of the disciplinary insights but not all insights could be approached more in depth. ▷ The presentation of the insights could be more coherent and balanced, not all relevant terms are clearly explained.	▷ The problem is challenging, well anchored in literature review, and its societal relevance is made clear. ▷ Shows thorough understanding of the (disciplinary) insights, assumptions, and context. ▷ Relevant terms and concepts are explained clearly. ▷ A clear justification is given why the complexity of the problem exceeds the boundaries between disciplines. ▷ The most relevant disciplines that relate to the problem are covered and well justified, as well as the ones left out.
2. PERSPECTIVE TAKING	▷ Shows no real open mindedness towards other ideas and beliefs. ▷ Does not question his/her own (disciplinary) biases and assumptions. ▷ Has difficulties including other viewpoints as part of the problem-solving process.	▷ Shows interest in other viewpoints, although superficially. ▷ Is reluctant to temporarily set aside his/her own viewpoints and beliefs. ▷ Values other (non-) disciplinary perspectives as a valuable addition, rather not quite as equally important.	▷ Open mindedness: appreciation of and genuine interest in different (personal and disciplinary) perspectives; ▷ Awareness of his /her own biases and assumptions and of the limitations of his/her own discipline. ▷ Values other (non-) disciplinary perspectives as a part of the problem-solving process.
3. COMMON GROUND & INTEGRATION	▷ Strengths and weaknesses of each disciplinary insight are quite superficial and based on preferences rather than critical analysis. ▷ Similarities and differences of disciplinary insights are there, but analysis and structure are lacking. ▷ Key concepts are not clearly defined. ▷ As a result, the disciplinary insights are presented next to each other rather than in a connected and integrated way.	▷ Clear analysis of strengths & weaknesses of most disciplinary insights, but not all aspects are elaborated on. ▷ The differences and similarities are analyzed, though somewhat superficially. ▷ Some key concepts are defined. ▷ An endeavor to find common ground is shown by trying to reconcile or connect disciplinary insights.	▷ Clear and critical analysis of strengths and weaknesses of each disciplinary insight, with respect to theories, methods and assumptions. ▷ Clear analysis of similarities and differences between disciplinary insights related to the research question(s). ▷ Key concepts are defined in neutral terms. ▷ Common ground has been found and is clearly explained. ▷ Integration of the disciplinary insights resulted in a new or reconciled understanding. The new insights are applied to the problem or case, providing new directions for solutions or answers.
4. CRITICAL REFLECTION & BROADER AWARENESS	▷ The reflection does not move beyond a description of the learning experience. ▷ The reflection hardly describes societal impacts nor explains what/who will be affected by the proposed solution. ▷ Potential limitations of the proposed solution are not or hardly addressed.	▷ The reflection provides some insights in the process of integration and learning gain, but the value of the learning to the student is vague and/or unclear. ▷ The reflection includes an indication of some societal impacts and moderately explains what/who will be affected by the proposed solution. ▷ Potential limitations of the proposed solution are addressed as well as some strategies to overcome them.	▷ The reflection provides valuable insight in the phases of the process, the challenges faced, and the learning gain. ▷ The reflection shows implications for future learning. ▷ The reflection clearly addresses societal impacts of the proposed solution and explains what/who will be affected. ▷ Potential limitations of the proposed solution are clearly described as well as solutions to overcome them.
5. COLLABORATION	▷ Is often too submissive or dominant in the collaboration process. ▷ Has difficulty in explaining his/her insights to peers. ▷ Respects and trusts the expertise of some of the team-members; ▷ Is willing to provide feedback but is not very open to feedback from others; ▷ Participates in exchanging priorities but does not take initiative. Has difficulties with compromising. ▷ Can be rude to peers.	▷ Listens to others but does not acknowledge whether he/she understands the other. ▷ Tries to explain his/her insights but shows some difficulty in doing so. ▷ Respects and trusts the expertise of most of the team-members; ▷ Is willing to provide feedback and is mostly open to feedback from others; ▷ Participates in exchanging priorities but does not take initiative. Is willing to compromise. ▷ Is aware of and sensitive towards the position of other team members.	▷ Listens with an open mind to other's personal and/or disciplinary perspectives. ▷ Explains in layman's words of one's own disciplinary perspective; ▷ Trusts and respects the expertise of team-members; ▷ Provides constructive feedback and shows openness to feedback from others; ▷ Clearly exchanges goals, priorities and values, and makes concessions to formulate a common goal; ▷ Aware of and sensitive towards the position of other team members and sees how disagreements can occur.
6. COMMUNICATION	▷ Has a hard time explaining disciplinary knowledge to a layman's audience, and finds it difficult to avoid jargon. ▷ Listens to others, but is rather judgmental. ▷ Is not always clear in communicating his/her findings.	▷ Is aware of the level of knowledge of the audience he/she is addressing but finds it difficult to avoid jargon. ▷ Listens to others, is open minded and non-judgmental. ▷ Is not always clear in communicating his/her findings.	▷ Is aware of the level of knowledge of the audience he/she is addressing. Can patiently explain disciplinary knowledge to others without using disciplinary jargon. ▷ Listens to others, is open minded and non-judgmental. ▷ Is able to effectively communicate his/her findings regardless of the medium used (writing, oral presentation, etc.)

↓

| 7. ADAPTABILITY & CREATIVITY | ▷ Isn't able to apply learned knowledge to new and unfamiliar situations or outside the familiar disciplinary setting.
▷ Stays within his/her comfort zone not daring to try something new or unfamiliar or gives up easily in trying new situations.
▷ Has a hard time in complex and unstructured situations.
▷ Discards ideas too soon or focusses on one idea from the start without thinking of other possibilities. | ▷ Tries to apply disciplinary knowledge in new and unfamiliar settings but gives up too easily or resorts to familiar ground if he/she doesn't reach a preferred result.
▷ Starts to venture outside one's comfort zone and explores new and/or creative ways to solve a problem.
▷ Takes risk but falls back on known patterns and working methods if things get hard. This limits the student's creative opportunities.
▷ Can come up with multiple ideas but finds it hard to determine which ideas will be useful in the end. | ▷ Thinks creatively in situations that are unfamiliar and doesn't give up easily.
▷ Thinks out of the box and takes risks because he/she realizes risk aversion stands in the way of originality.
▷ Sees challenges as an opportunity to develop and, if mistakes are made, sees them as a learning opportunity.
▷ Is aware that interdisciplinarity problems often do not have a right or wrong answer. |

Others before you

LEARNING FROM OTHERS' EXPERIENCES

Kelly *et al.* (2019) wrote a paper with practical advice in the form of 10 tips for early career researchers (and their mentors, including senior researchers and lab leaders) interested in interdisciplinary research. They based their advice on interviews with 13 leading practitioners from around the globe largely involved in interdisciplinary research topics in the field of aquatic and marine research. The interviewees had the following disciplinary backgrounds: oceanography, biology, mathematics, geography, sociology and natural resource management. Although these disciplinary experts did not consider themselves *inter*disciplinary experts, their diversity of experiences and perspectives make the recommendations below useful for less experienced researchers entering interdisciplinary projects.

The 10 tips also relate to skills and personality traits that researchers need if they hope to work effectively across disciplines, such as humility, respectfulness, open-mindedness, patience and a disposition to work with others under challenging circumstances. While these so-called 'soft skills' are consistently identified in the literature as critical for collaboration among disciplines, to date they are rarely valued, recognized or trained within postgraduate research training.The 10 tips for interdisciplinary researchers below are grouped in the so-called KAP-framework: Knowledge, Attitudes and Practices.

DISCLAIMER
The 10 tips below are well in line with the core messages of this booklet. If you have read part II, you will recognize most of them. The reason we still include all of these tips here is that while they might be repetitive, they are not redundant: so far, we have been informing you based on the literature, however, the following recommendations come straight from the mouths of real-life practitioners of interdisciplinary research, reinforcing our points. As such, we deemed them a valuable contribution in right of their rooting in experience.

TIPS RELATED TO KNOWLEDGE

Tip 1 • *Develop an area of expertise – work on your core*
Although interdisciplinarity means bridging between disciplines, a core grounding is required to bring your expert perspective to the interdisciplinary table comfortably, confidently and competently! This "core" knowledge, however, does not necessarily be a discipline, it can also be a field of study, a method (e.g. modeling) or a process. A core grounding could even be interdisciplinarity.

Tip 2 · *Learn new languages – seek to understand and speak across disciplines*

Interdisciplinary collaboration requires expression of disciplinary knowledge in understandable language. Within disciplines we are trained to use jargon as we speak about disciplinary knowledge, methods or techniques. Jargon makes it specific and exact for insiders, but usually confusing and excluding for others. In developing a shared language during collaboration, the challenge is not to lose the rigour and nuance of (new) terms. Superficial ability to function and communicate may come quickly, but fluency to work through language barriers takes time, immersion and patience. This time investment will pay off in the long term as it will increase flexibility and adaptability to work across disciplines and your ability to create interdisciplinary questions and solutions.

To learn new languages can for instance be done by listening & questioning, by sharing disciplinary definitions or key introductory texts, as well as by communication tools such as metaphors, stories and analogies.

TIPS RELATED TO ATTITUDES

Tip 3 · *Be open minded – appreciate diversity in perspectives and contributions*

To navigate across disciplines can be confusing and intimidating, especially if you have been trained to operate within the norms and rules of a single discipline. Important is to remain open-minded, open to learning new ways of doing things. An important aspect is to remain humble when collaborating with other disciplines. Invite questions, ask them to explain and don't be afraid to ask questions or indicate that you didn't understand.

Tip 4 · *Be patient – Interdisciplinary research takes time*

Establishing successful interdisciplinary collaboration requires (lots of) time. Often collaborators need to understand different disciplinary cultures, languages and approaches. Hence, across all stages of the research process, more than usual time is required for reflection and learning from each other. What is often expressed is that trust among members of the interdisciplinary research team is crucial, because this type of research can be uncomfortable, sometimes frustrating and definitely requires patience. Therefore, investing time to build trust and encourage social bonding processes is often considered to be a prerequisite. For many researchers, this type of time investment is challenging as it is not often supported by the academic reward system.

Tip 5 · *Embrace complexity – it can be stimulating and rewarding*

Differences in approach to complex problems are often experienced as roadblocks. The essence of interdisciplinarity, however, is that complexity and different perspectives are embraced and everyone's contributions appreciated. The complexity and ambiguity of interdisciplinary research, although often experienced as difficult, should be considered as opportunities rather than barriers. Working to understand the 'bigger picture' by combining views and knowledge from several disciplines provides a richer perspective and may open up doorways. As one of the interviewees expressed: "Many times when I'm reading a paper from another discipline or struggling through that terminology, I may suddenly go: 'Oh wow. I never would have thought of that' and it helped me to find common patterns across scales that you wouldn't have appreciated otherwise".

TIPS RELATED TO ATTITUDES & PRACTICES

Tip 6 · *Collaborate widely – and check your ego at the door*

Interdisciplinary work is all about collaboration and to discuss the expertise that all participants can bring to the table. Appreciating differences in views and knowledge and at the same time respecting other perspectives will help in co-creating research questions and to find a balanced outcome in teams of interdisciplinary researchers. Hence, every individual is important; egos, however, will impede fine-tuned collaboration and hamper the progress of the research process. As interdisciplinary team members share an interest in working on the challenge at hand, joint learning can be a fruitful product of the collaboration.

Tip 7 · *Push your boundaries – get comfortable outside your comfort zone*

Interdisciplinary research provides an excellent opportunity to challenge yourself to broaden your perspective as well as to comprehend a complex problem differently. Exposing yourself to novel opinions and perspectives (by reading or attending seminars outside of your discipline) as well as to get outside of your comfort zone are useful activities to nourish this type of attitude. Broadening your disciplinary perspective may promote novel and innovative approaches to tackling complex research challenges.

TIPS RELATED TO PRACTICES

Tip 8 · *Consider if (and how) you will engage in Interdisciplinary Research.*

It is not necessary that interdisciplinary career paths will appeal to everyone. It is also very important that many will address relevant and critical questions within their own discipline. Although a career in interdisciplinary research can bring a lot of satisfaction in providing compelling solutions to complex questions with your team, you should realize that it is a challenging path that requires patience and perseverance. Also, some additional skills and competencies are required, described in more detail earlier in this booklet, in comparison with those necessary for disciplinary research. It is therefore important that you identify your personal aspirations and skills before embarking on any of these options.

Tip 9 · *Foster interdisciplinary culture – support researchers at the grassroots level.*

In order to create an environment in which interdisciplinary research can take place successfully, it is of importance that institutional leaders and senior scientists foster open atmospheres and create safe spaces for this type of research. Only when lab groups and researchers have the freedom to think and work across disciplinary boundaries, an interdisciplinary culture can be created. To ensure that interdisciplinary work is valued, institutional leaders may additionally allocate resources (time, meeting spaces, finances) and arrange (in)formal recognition and encouragement of career progression such as interdisciplinary skill development.

Tip 10 • *Champion researchers – showcase examples of interdisciplinary success*

High quality interdisciplinary research deserves recognition, akin to that awarded within disciplines for academic contribution and practical output. Praise and recognition are central to improving researchers' track records and may motivate other disciplinary researchers to participate in interdisciplinary work.

WHAT MAKES INTERDISCIPLINARY TEAMS SUCCESSFUL?

Analysing collaborations in the field of sustainability, Freeth and Caniglia (2020) identified five dimensions that categorize the kinds of challenges interdisciplinary groups may face. These encompass the epistemic, social, symbolic, spatial, and temporal dimensions.

▶ *Epistemic:* The epistemic domain refers to assumptions about research and knowledge. Problems might arise in this domain because people of different academic backgrounds might disagree on what the main aim of research is, what the research question is and how it can best be answered.

▶ *Social:* The social domain refers to the interpersonal relationships of the people involved in the project, and includes emotional dynamics and trust in each other.

▶ *Symbolic:* The symbolic domain is about power relationships in the project, for example how the group is organized.

▶ *Spatial:* The spatial dimension is about the space that the group works in. Does it meet the needs of the individuals working on the problem?

▶ *Temporal:* The temporal domain refers to the time management, like the pace of the project, deadlines, and time frames.

Some of these challenges may arise in any kind of collaborative project, while others are more relevant for interdisciplinary challenges specifically. Problems in the epistemic domain for example, are more likely to occur in interdisciplinary projects. Additionally, problems in the symbolic domain are relevant for all kinds of collaborative problems, but might look different in interdisciplinary projects because the power relationships between disciplines can add a new dimension to the problems.

To master the interdisciplinary challenges as a team, Freeth and Caniglia (2020) suggest three categories of collaborative competencies, namely 'orientation', 'knowledge', and 'skills'. These roughly correlate with the 10 tips for interdisciplinary researchers developed by Kelly *et al.* (2019), which were described above.

FURTHER READINGS

Popular science books on interdisciplinary topics

Bryson, B. (2004) *A short history of nearly everything.* Broadway Books.
▶ Bryson tackles the ambitious project to understand and explain how things came from nothing at all … to there being us. To do so, he consults archaeologists, anthropologists, and mathematicians.

Changizi, M. (2011). *Harnessed: How language and music mimicked nature and transformed ape to man.* BenBella Books, Inc.
▶ The development of (human) language is tackled using insights from (psycho)linguistics, evolution and physics to explain how languages and the sounds they entail evolved.

Dawkins, R. (1976). *The selfish gene.* Oxford University Press.
▶ This book had a large impact in Biology, putting the gene center-stage. According to many, this book is "the mother" of all popular science books.

Diamond, J. (1997). *Guns, germs, and steel: the fates of human societies.* W. W. Norton
▶ An intriguing analysis of the origin of inequalities (why Eurasian peoples conquered or displaced Native Americans, Australians, and Africans, rather than vice versa) over the past 13.000 years, written from the perspectives of anthropology, biology, geology, history and sociology.

Harari, Y.N. (2015). *Sapiens: A brief history of humankind.* Vintage UK.
▶ This book is widely popular for sweeping the reader through the development of humankind – evolutionarily, culturally, technologically, … - from its beginnings all the way to the present moment.

Henrich, J. (2016). *The secret of our success: How culture is driving human evolution, domesticating our species and making us smarter.* Princeton University Press.
▶ Drawing from neuroscience, genetics, archaeology and anthropology, Henrich explores how humankind taps into a collective intelligence that accounts for our unique achievements.

Kahneman, D. (2011). *Thinking fast and slow.* Farrar, Straus & Giroux Inc.
▶ Are we as rational as we think when making decisions? This is considered to be one of the most influential books of the decade.

Kandel, Eric R. (2012). *The age of insight: The quest to understand the unconscious in art, mind and brain, from Vienna 1900 to the present.* Random House.
▶ Eric Kandel, Nobel prize winner, examines the intersections of psychology, neuroscience and art using Viennese culture of the twentieth century as a historical lens.

Pollan, M. (2001). *The botany of desire: A plant's eye view on the world.* **Random House.**
▶ Pollan questions the hierarchy between humans and plants: Who domesticates who? Starting from the desirable characteristics of some of the most popular domesticated plants, he studies human beings from a new angle.

Wilson, E.O. (2012). *The social conquest of Earth.* **W.W. Norton & Company.**
▶ Edward Wilson, one of the world's preeminent biologists unfolds a powerful origin theory that traces life's evolution from its cellular origin to the present human civilization.

Wilson, E.O. (1998). *Consilience: the unity of knowledge.* **Little Brown UK.**
▶ A journey across the sciences and humanities in search of deep laws to unite them.

**Textbooks on interdisciplinarity and interdisciplinary research**

Augsburg, T. (2016). *Becoming Interdisciplinary; An Introduction to Interdisciplinary Studies (3rd edition).* **Kendall Hunt Publ. Company.**

Frodeman, R. Klein, J.T. and Pacheco, R. (eds.) (2017). *The Oxford Handbook of Interdisciplinarity (2nd ed.).* **Oxford University Press.**

Repko, A.F., Szostak, R. and Buchberger, M.P. (2020). *Introduction to Interdisciplinary Studies (3rd edition).* **SAGE Publications.**

Repko, A.F. and Szostak, R. (2021). *Interdisciplinary Research; Process and Theory (4th edition).* **SAGE Publications.**

UP TO YOU
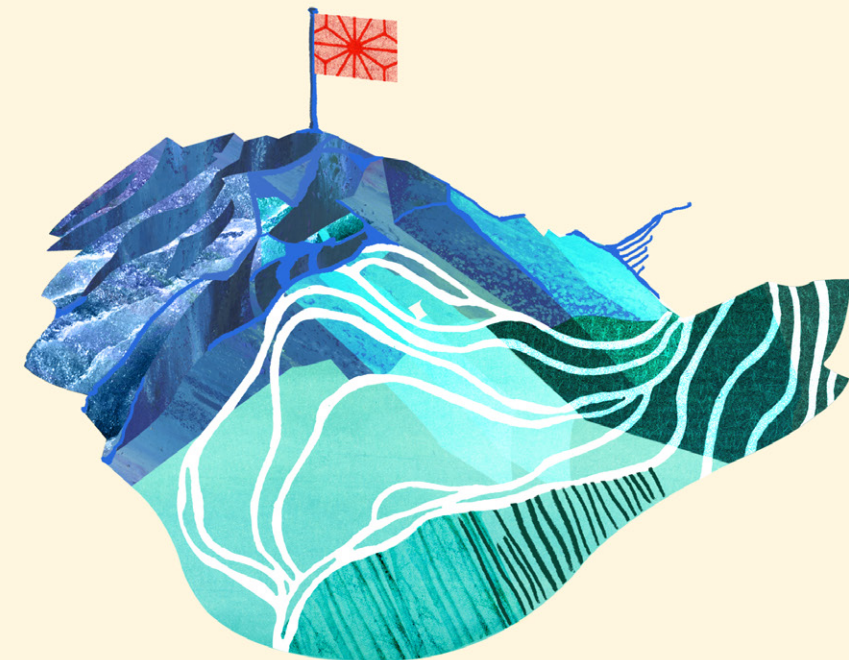
We have talked enough. If you have made it to here, you've probably taken in a lot of information; now it's up to you to make something of it. Below you will find some prompts to help you get started in engaging with interdisciplinary work. For all of these activities, consider: Whatever you can externalize and get feedback on will benefit you more - hence, don't just think. Write, draw, talk, ... and most of all, share with others!

UP TO YOU

Exercises
to get you started in practice

For some intellectual practice specifically targeted at interdisciplinary competencies, this section provides you with exercises and assignments that you may like to tackle. They help you develop the competencies and qualities we have addressed in part II and allow you to make some interdisciplinary experiences for yourself. You may recognize some of these exercises as particularly aiming at some of the four learning goals you can read about in part III of this booklet ("You in an Interdisciplinary Team").

Tip · Pay attention to what feels familiar or easy as you explore the "Up to You" boxes and delve into the exercises below. You may start to notice the pool of experience and qualities related to interdisciplinary work that you already have in store. Acknowledge and appreciate them, foster them and observe how you can best employ them to help you navigate and expand on whatever new ground you may find in the course of your interdisciplinary adventures!

1. *Writing in your discipline*
A simple exercise to help you determine how your discipline differs from others is to read a research paper of your interest from a completely different field. The objective of this assignment is to become aware of differences in communication styles between disciplines. Pay attention to the rhetorical conventions of writing in a discipline that is foreign to you and compare these with the way you write your research papers, or with the way that papers in your discipline are written.

2. *What is a discipline?*
As interdisciplinary studies build on disciplinary insight, it is important to recognize the defining elements of disciplines, namely: the phenomena they study, their epistemology, assumptions, theory, and methods. In this assignment, try to describe the defining elements of your discipline, using the "hand-out" below. When you feel you have gotten the gist of the exercise and understand your discipline's workings better, you can start doing the same with other disciplines. The objective is to learn what kinds of phenomena are being studied in different disciplines, and how. What are the basic concepts on which this discipline builds? Try to grasp its underlying epistemology and the assumptions that shape it, as well as the theories and methods that define the discipline's approach.

Since this assignment is theoretically challenging, it will be helpful (if not necessary) to discuss it with others and go explore what you can find on the internet (you might come across some good YouTube videos or TED talks).

Hand-out: Defining elements of your discipline (see Repko et al. 2020)

▶ **Phenomena**
  ▷ the subjects, objects, and behaviors that a discipline considers as falling within its research domain.
▶ **Epistemology**
  ▷ the nature and basis of knowledge; concerning questions such as:
  How do we gain knowledge and what is it, really? How can we know what we know? What is truth / Is there truth? How much can we know? Is knowledge reliable / stable across time and space? Etc.
▶ **Assumptions**
  ▷ things that are accepted as true or certain. Assumptions reflect mostly epistemology, but capture elements of ethics, metaphysics, and ideology when these are particularly important.
▶ **Methods**
  ▷ particular procedures, processes and/or techniques used by a discipline's practitioners to conduct, organize and present research.

MY DISCIPLINE IS:	
Phenomena	
Epistemology	
Assumptions	
Methods	

3. *The value (and limitations) of your own discipline*

Think of the strengths and limitations of your own discipline. What is it that makes you proud of your own discipline? What makes you doubtful? Keep a logbook for some time (6 months is a good start) in which you write down insights, experiences or news articles, on which you can describe the value of your discipline. Are there specific concepts, research strategies, research results, modes of thinking, ... that you consider to be remarkably positive characteristics of your discipline? Are there any such things within your discipline that you are skeptical about? It might be nice to do this assignment together with friends (from your own or from different disciplines) and get together to discuss your notes once in a while. You could also make a mind map, fact sheet or infographic on your findings and ask for feedback from your fellow students.

4. *Points of view*

A method to help you cultivate awareness of different perspectives is to examine an issue through a specified lens other than your own disciplinary lens. Think about an issue that is important to you (for example, vegetarianism, data privacy, free speech, LGBT rights, ...) and examine that issue from the lens of a practitioner (a farmer, a programmer, an advocate, ...), and of academics from different disciplines (an economist, an ecologist, a philosopher, a sociologist, a biologist, ...) as well as through the eyes of the general public. It will help to use all sorts of different sources to inform your reflection: google scholar, forums and blogs, social media, news items, papers and homework from your own or your friends' past school and study times, etc.

5. *Text-ballooning a journalistic essay*

Pick a non-scientific text, for example a relatively short policy document, a speech, or a long newspaper article. Close-read the text and try to pinpoint from which disciplinary view(s) the arguments are drawn. Do the following:

▷ Add at least 10 comments in comment balloons (in Word or PDF), each of which singles out an argument and identifies in which discipline the argument is grounded.

▷ Search for instances in the text where insights from different disciplines converge. Wherever you find one, add a comment balloon and explain how the disciplines converge.

▷ If you do this exercise with a peer, swap your files with the comments and discuss them: Do you disagree on something? Is everything clear? Is anything surprising?

6. *Analyzing the interdisciplinary perspective of a paper*

Read the following paper by Christiansen & Kirby (2003):
Christiansen M.H. & Kirby S. (2003). *Language evolution: consensus and controversies.* *Trends in Cognitive Sciences,* 7(7): 300-307. https://doi.org/10.1016/S1364-6613(03)00136-0
And analyze its interdisciplinary perspective. To do so, you can fill in the table below, either alone or together with others who have read the paper. Check or discuss the presence or absence of the various interdisciplinary working steps devised by Repko. You can find an explanation of Repko's steps under the heading of "Interdisciplinary Methodology" in part II of this booklet.

Hand-out:

CRITERIA	YOUR ASSESSMENT OF THE PAPER
Phase 1: RESEARCH QUESTION	
a. The author defines the problem in a clear way that is appropriate for an interdisciplinary study	
b. The relevance of the study is made clear	
c. It is explained why an interdisciplinary approach is taken	
d. Possible contributions of each discipline are made clear	
Phase 2: DISCIPLINARY FINDINGS	
a. Disciplines or disciplinary insights relevant to the problem are explained	
b. Differences between disciplinary insights are identified/ presented	
c. Strengths and weaknesses in theories and methodologies are presented	
Phase 3: INTEGRATION	
a. Common ground (some sort of common denominator) is presented.	
b. The combination of theories and/or methodologies are integrated into a more comprehensive understanding.	

7. *Creating a concept-map*

Concept-maps are graphical tools for organizing and representing knowledge. They allow you to structure your knowledge about an issue from diverse disciplinary perspectives and synthesize knowledge (hierarchical and/or linear and/or loops) between them. Select a topic of your interest, then

▷ Write down major terms or concepts that are relevant to the topic on separate sticky notes (for instance, you can browse articles on the topic and make a list of recurring words)

▷ Sort through the sticky notes, putting aside terms you don't understand and terms that don't seem to relate to any of the others.

▷ Arrange the sticky notes such that related terms are positioned closer to each other. Leave space for lines.

▷ Draw lines between concepts that you consider to be related and write on each line the nature of the relationship that connects the concepts.

▷ In the process, create new sticky notes for more concepts that you think of.

▷ Go back to the notes you put aside and see if some of them have become clearer or can now be fit into the concept-map.

▷ When you feel that your concept-map is finished, don't forget to put the topic at the top or the center. If you want, you can find someone who is more familiar with the topic than you are and ask them to go over the concept map with you to improve or complete it.

8. *Teamwork: your skills & ground rules*

In multi- and interdisciplinary research or assignments, you usually work together with individuals from different disciplines. Hence, teamwork skills are important. Below you'll find a number of suggestions to become more aware of what is required to contribute to an effective team. You can partly do these exercises individually, but some of them might be good for other members of your team to complete as well, so you can evaluate them together and learn some lessons during group work.

8A. *Your teamwork skills*

Learning to collaborate in teams starts with being aware of your own strengths and weaknesses. Below you'll find a list of teamwork skills. Indicate how satisfied you are with your own skills and answer the reflection questions below the table.

TEAMWORK SKILLS	Not satisfied	Somewhat satisfied	Very satisfied
1 Reliable and committed (taking responsibility and being accountable)	○	○	○
2 Communicative (explaining your thoughts clearly)	○	○	○
3 Active listening (listening carefully and asking questions to clarify others' ideas)	○	○	○
4 Participate actively (being prepared and contribute constructively)	○	○	○
5 Sharing your ideas (readiness to share your knowledge & feelings with the team)	○	○	○
6 Flexible (Compromising when necessary to move the group forward)	○	○	○
7 Creative problem solving (being able to come up with solutions & new perspectives)	○	○	○
8 Conflict resolution (being able to mediate problems between team members, focusing on solutions rather than blaming others)	○	○	○
9 Respectful (conveying respect for others and for their ideas)	○	○	○

Reflection on your teamwork skills:
1) I am proud of my ability to: ....
2) I intend to improve my ability to: ....

You can share your reflections with your team, so your mates can help you improve. If they participate and you put all your tables and reflections together, you can find out the strengths and weak spots of your team as a whole. This is extremely helpful because it allows you to discuss how to cope with the collective weak spots and how to make the most of your collective strengths in a team effort.

8B Establishing ground rules of a team

Many of you have enough (positive and negative) experience working in groups to be able to design some ground rules for successful collaboration. You can write down a number of rules for yourself, but also for your team together with your team. Sharing this information can improve team cohesion and effectiveness.

Instructions:
  a. It is sometimes easiest to give advice in light of bad experiences and how to avoid them. Take a few minutes to envision and write down your suggestions for a disastrous group process.
  b. Exchange your suggestions and design a "top 5" of ground rules you all want to commit to in order to avoid disaster and promote the opposite: a successful group process. Also discuss how the team will act when these rules are not respected (what are the consequences?).
  c. Exchange expectations. Some students strive for a high grade, while others simply want to pass. Some like to begin projects in advance, while others need the pressure of a deadline to do work. This can create tension because the group is not working towards the same goal and often the wrong promises or unnecessary concessions are made. Exchanging your expectations at an early stage is key to making sure everyone is on the same page and optimally also gets to work under their best circumstances. For instance, remember that it is not necessary for everyone to work at the same time! Take about 10 minutes to discuss your expectations and goals and draw up an optimal procedure plan.
  d. Remind yourselves once more of the ground rules you have established before you get to work.

8C Teamwork evaluation

Even if your team is doing well and you get along splendidly, it helps to check the quality of your teamwork on a regular basis. This way, you prevent accumulating things left unsaid, which could create problems later on. You can use the information below to evaluate your teamwork by:

  1. Filling in the form individually
  2. Making an inventory of your answers, and
  3. Discussing the most remarkable differences and the least positive issues.
  4. Lastly, discuss the way you want to improve your teamwork.

TEAMWORK EVALUATION FORM	Fully disagree			Fully agree
In this team, we listen to each other	1	2	3	4
In this team, I feel free to voice my opinion	1	2	3	4
We appreciate each other's contributions	1	2	3	4
Some people hardly speak in this team	1	2	3	4
We mostly follow the ideas of the same one or two people in this team	1	2	3	4
We motivate each other	1	2	3	4
I feel comfortable in this team	1	2	3	4
In this team, people are open to new and unusual ideas	1	2	3	4
Team problems are being discussed openly	1	2	3	4
We work hard in this team	1	2	3	4
We should discuss options more in depth before choosing a solution	1	2	3	4
I am learning a lot from others in this team	1	2	3	4
This is a productive team	1	2	3	4
We all give our best in this team	1	2	3	4
We are a well-organized team	1	2	3	4

Head space
for further orientation

After the many pages of input, the following empty pages are all yours! They provide you with space to empty your mind through whatever works best for you: writing or drawing and collecting ideas, remarks, dreams, ambitions, doubts and questions on interdisciplinarity and your relationship with it. Maybe a mind-map is a good start?

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"Interdisciplinarity" has become a buzzword in education in recent years, with good reason. Many regard interdisciplinary education as necessary to equip students to tackle the increasingly complex problems that human society is facing, often at a global scale. Amongst employers, there is a growing demand for a new generation of professionals with both in-depth disciplinary training and the ability to think and work on a broad level in collaboration with experts from other disciplines. To meet these demands, universities worldwide have been starting to incorporate inter-disciplinary assignments, courses and even curricula in their programs.

This booklet aims to get you acquainted with interdisciplinary work. Whether you already have some experience with interdisciplinarity or are new to this approach, the pages you're holding can act as a guide to help you orient yourself and navigate beyond your own discipline. They provide you with a basic understanding of interdisciplinarity, its potential, diffi-culties, underlying ideas and historical roots. We also give you plenty of pointers to paths you can take if you want to further explore interdiscipli-nary research and get to know yourself better on the way. If you catch the balls we throw you, you can get a good idea of what it may be like for you to work in an interdisciplinary environment and how you can continue to develop in this direction.

We hope you enjoy reading and find inspiration to expand your academic toolkit!