The Role of Empathy in the Practice of Nanobiology: A discussion of the status and transmission of personal and tacic knowledge in natural science

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0. Introduction

Personal background

This thesis will discuss the scientific relevance of personal knowledge in natural science, and the role of empathy in scientific practice. These themes are usually not immediately associated with natural science. The relation between these themes became apparent to me during my experiences as a student researcher in the department of Bionanoscience at Delft University of Technology in 2020–22.

As a part of my Master's program in Applied Physics, I carried out a 10-month research internship in one of the labs at the Bionanoscience department at the TU Delft. As a member of the Gijsje Koenderink Lab, my research focused on building one small part of the human cell, the cytoskeleton, synthetically. This research was part of the global effort to build a synthetic cell (BaSyC, 2022). Being a part of the lab and the scientific practice was interesting from the perspective of philosophy of science as well as the perspective of biophysics and nanobiology. I noticed that the reality of the scientific practice is often less rational and objective than people, even scientists themselves, expect it to be.

During my time in the lab, I had the impression that my colleagues acknowledged some aspects of practice as scientifically sound and justified, and others not. The misunderstanding of these latter aspects as unscientific reminded me of the texts that I had read on feminist philosophy of science, on the imbalance in 'feminine' and 'masculine' values and methods in science. 2020 was also the year that images and representations of the traditional *Zwarte Pieten* had almost completely disappeared from shop windows in the Netherlands (at least in the Randstad), and personal experiences and corresponding feelings of individuals were increasingly well understood and acknowledged: Empathy seemed to gain importance as a value in society. Here, these themes will be combined, and I will try to show how empathy for other people is relevant even in the daily activities of a natural scientist. Despite its emotional character and the usual classification of empathy as something that has no business in natural science, I will endorse its unique value in the field of nanobiology.

Philosophical problems

In this thesis, I consider those aspects of the scientific practice that my fellow scientists seemed to dismiss rather than acknowledge. Nanobiology is a relatively new field of science. In the objects and samples that an experimental researcher in nanobiology studies, effects from the fields of chemistry, physics, and biology all have a significant contribution. Furthermore, the methods and equipment that is used for the experiments and the measurements are in full development. This means at least two things. The first is that there are many things unknown. Therefore, the scientist must rely on other resources than theory (even more than scientists are usually forced to). Secondly, as a result of the novelty of the field of science and its methods and equipment, the experimental, physical, know-how of a scientist becomes of key significance in the lab. In short, the scientific practice of nanobiology forces scientists to master highly specialized motor skills, and make intuitive decisions on a daily basis.

The problem with these two consequences is that they require certain types of knowledge and methods that are not widely accepted as scientific. Nanobiology is a natural science, aiming to create objective knowledge. Even though nanobiology studies objects that should behave the same, given equal conditions, its scientific practice requires a fair amount of untheoretical reasoning and subjective knowledge. One of the problems that I am concerned with, is this tension, between objective, law-like, general knowledge that nanobiology pursues, and the means required to attain it.

Even if subjective knowledge is accepted as scientific knowledge, it remains problematic as it stands. Scientists are often unhappy about it, they feel like it is a necessary evil. Possibly as a result of that, this knowledge is often not transferred properly. In addition, the fact that subjective knowledge is usually personal, only accessible to its owner, does not make it easier. There is no clearly defined method for the transmission of subjective knowledge. So, even if these types of knowledge are accepted as scientific, which happens in some cases in the practice of nanobiology, we have extreme difficulty with treating them as such. The mainstream scientific discourse does not allow for the transmission of the types of knowledge and the application of the methods that are required in nanobiology.

Relevance and contribution

In this thesis, I argue that the solution to the problem regarding the recognition of subjective knowledge required in nanobiology can be found in feminist philosophy of science. There is good reason to believe that subjective knowledge is practically inevitable, and philosophically acceptable in scientific action and decision-making (Keller, 1995; Anderson 1995; Harraway, 1988, Rödl, 2019). Furthermore, I propose a solution to the problem regarding the transmission of subjective knowledge. My approach to the philosophical problem of personal knowledge is slightly different from the problems described in the literature (Collins, 2010; McAllister, 2015; Boesch, 2019), as I consider the transmission of personal knowledge to be the problem, not personal knowledge itself. I will suggest that empathy is the method that is now used to transfer subjective knowledge, where it is acknowledged. In addition, I will suggest that empathy as a method has the potential to enable scientists to transfer subjective knowledge also where it has failed to be recognized as scientifically relevant, or to be transferred as such. As far as I know, the relation between the transmission of personal knowledge and empathy is a novel contribution to contemporary philosophy of science.

Throughout the thesis, I use my personal experiences as cases and examples to show how subjective knowledge functions and how it is or fails to be transmitted. Nanobiology is a suitable branch of science to focus on in order to make this point. The role of subjective knowledge is apparent, because of factors mentioned above. The themes discussed in this thesis, however, might be relevant to all natural sciences. And the conclusions might even apply to the transmission of all subjective knowledge.

Research questions

The main research question of this thesis is: What is the role of empathy in the scientific practice of nanobiology? I mean to consider both the current role empathy plays, and the possible role of empathy in an ideal scientific practice in nanobiology. To answer this main question, other questions are addressed first. Considering the philosophical and practical problems in nanobiology that I introduced above, I will address the sub question: What is the role of personal knowledge in the practice of nanobiology as it stands? I will argue that personal knowledge is a significant and indispensable component of the scientific activities in this field. This raises two further sub questions: How can personal knowledge be accepted in methods of natural science? And, How can personal knowledge be transmitted? In order to answer the main research question, I need furthermore to answer the sub question: What is empathy? Answering all sub questions will allow me to consider the current role of empathy in nanobiology as well as the potential role of empathy in this practice.

Chapter development

In chapter 1, I address the first sub question and assess the role of personal knowledge in nanobiology. I give a conceptual analysis of the different phases in one scientific cycle, and the corresponding activities. Based on this conceptual analysis, I identify two roles of personal knowledge, that I will elaborate using examples from the scientific practice. I proceed with a chapter containing the philosophical analysis of these two functions of personal knowledge, and their philosophical implications, using contemporary literature in philosophy of science. I close chapter 2 with a critical analysis of this literature and a conclusion on the philosophical problems that remain, regarding personal knowledge in nanobiology. In chapter 3, I address one of them, the problem regarding the acceptance of the use of personal knowledge in natural science. I answer the corresponding sub question by discussing my reading of contemporary literature in feminist philosophy of science. After I set out a philosophical framework that allows for the use of personal knowledge in natural science, I continue with discussing its transmission. Chapter 4 starts out by answering the sub question: What is empathy? By evaluating literature from the tradition of phenomenology and philosophy of science on empathy. The chapter proceeds with a discussion on the transmission of personal knowledge in nanobiology. In this discussion, I base myself mainly on examples from my personal experiences, and the experiences of other researchers in nanobiology from my former lab. The experiences of the other researchers were acquired and reported in an interview I conducted at my former research group in Delft. In the discussion, I provide a critical assessment of the assumptions and claims in this thesis. Finally, I reflect on the conclusions and on the answers to the research questions I posed earlier in this introduction. After the conclusion, I add a word of thanks.

1. The role of personal knowledge in the scientific practice of nanobiology research

Preview of this chapter

In this chapter, I describe the current state of the scientific practice of nanobiology and the role of personal knowledge in this field. I subsequently clarify the problems that lead to the research questions dealt with in this thesis. The goal of this chapter is to identify the roles that personal knowledge has in the scientific activities of an experimental researcher in nanobiology and to evaluate the philosophical implications of this influence. I will start with a conceptual analysis of all main scientific activities in nanobiology and evaluate the role of personal knowledge therein. I give some examples, to bring to life the functioning and scientific relevance of personal knowledge. Then, I discuss some contemporary philosophical views of the functions of practical knowledge in natural science that we identified earlier. Finally, I formulate a philosophical evaluation: I propose a perspective on the problems that come with personal knowledge in natural science, and formulate the philosophical questions that arise. These are the questions that I will answer in the following chapters.

The examples and insights mentioned in this chapter are largely based on my personal experiences in the lab, from my time in the Nienke Dekker Lab and the Gijsje Koenderink Lab at Delft University of Technology in 2018/2019 and 2020/2021. Some experiences of other researchers that I acquired through interviews will be used too.

Clarification of concepts

Before diving into the analysis of the scientific practice of nanobiology, I want to clarify the concept of *personal knowledge*. In this thesis, the term personal knowledge is used to refer to knowledge that depends on the individual, their personal experiences, their body, or other factors accessible only to a particular individual. It is opposed to objective knowledge. *Personal* applies to the justification or origin of the knowledge, and not necessarily its content. One can have personal knowledge of a general law/mechanism or an objective fact.[1] The difference between objective and personal knowledge is its source, not its content. The justification or source of objective knowledge is accessible for anyone (at least in principle), through publications, etc. The justification of personal knowledge is not accessible to anyone, because the source of personal knowledge lies in the experiences and minds of the individual. Knowledge can even be personal when it is also available as objective knowledge. For example, one can conclude from their own observations, that they use more fuel when they drive a car at 130 km/h compared to when they drive it at 100 km/h. This is a fact that is also available theoretically. One might have this knowledge as personal knowledge instead of objective knowledge. Personal knowledge is subjective, because it depends on the individual

[1] I use the terms 'theoretical' and 'objective' to indicate different kinds of non-personal knowledge: both conceptual, analytic, *theoretical* knowledge, and *objective* empirical knowledge, or empirical knowledge that has been replicated, verified, and accepted by the scientific community. Both kinds of knowledge are not subjective, but objective. Theoretical knowledge is covered by objective knowledge, so the term 'theoretical' may be skipped here. I mention it explicitly in addition to objective knowledge, to show that the distinction that I make between personal and objective knowledge does not refer to the content, but about the source, justification, and availability of the knowledge.

who holds it. Personal knowledge might turn out to be wrong. Theoretical and objective knowledge can also turn out to be wrong. However, personal knowledge is often less verified and more subject to local factors than objective knowledge is.

1.1 The scientific practice of nanobiology

In this chapter, I will give a brief, conceptual overview of the different scientific phases of experimental research, and succinctly analyse the function of personal knowledge therein. Here, I will jump to conclusions quickly, and identify two main functions of personal knowledge in nanobiology. In chapter 1.2, there is a precise and detailed discussion on how personal knowledge functions in scientific practice, including numerous examples.

Brief introduction to nanobiology

In nanobiology, we aim to answer questions about the smallest biological components. These are the fundamental building blocks of life on earth(proteins, lipids, DNA). nanobiology is the science where we question and discover the fundamental principles and processes of life. Common subjects include for example DNA replication and cell division. We try to discover the minimal requirements for cell division, or DNA replication, for example. These examples show some driving questions behind many of the nanobiology research nowadays. (For more information, consult TU Delft (2022) and The Biophysical Society (2022))

To answer these questions, many scientific disciplines that were once separated, now have to join forces. Physicists are needed to build measurement devices that can measure samples at this scale. Furthermore, phenomena[2] that belong to the realm of physics, biology, and chemistry, all significantly affect the mechanisms of interest.

Analysis of personal knowledge used in each experimental phase

Despite the special circumstances required for most experiments and the complexity of the interdisciplinary theory, the scientific activities of a nanobiologist are conceptually very similar to those of any experimental research project in natural science. One takes the following steps[3]: 1. Formulate a hypothesis and/or define a research question, 2. Design an experiment (on paper) to test that hypothesis or answer that research question, 3. Develop the method, which means, get the experiment to work in the lab, 4. Collect data, and 5. Analyse the results. After these steps, one returns to step 1: based on the analysis and interpretation hypothesis, one defines a new research question, etc. I will now evaluate the role of personal knowledge in each of these phases. In the next chapter, I will discuss some explicit examples.

1. <u>Defining a research question.</u> Defining a research question can happen on any scale. One can define a research question for an entire project, spanning multiple years, or a subquestion that concerns only the reproducibility of one particular experiment. When an entire project is set up, researchers study the existing literature and find some gaps or open questions that they want to work on. When the research question is based purely on published papers, we would say that its formulation is a theoretical effort. However, researchers often get inspired by their personal experiences in the lab. This is more apparent on the scale of an experimental subquestion. Every

[2] Electromagnetic forces, surface tension, and protein affinity can all significantly affect one single situation, for example.
[3] This is my own analysis.

experimental result creates a new hypothesis in the researcher's mind. Every answer raises another question: why? How? Under what circumstances? The formulation of a question can thus be based on both theoretical and personal knowledge and motivations. When a research question is based on personal experiences from one's own research, an experiment or result that has not been described by theory, then we say that personal knowledge (experience) guides that question. In this way, personal knowledge informs the direction of the research and guides scientific decisions.

2. Designing an experiment. Initially, the method is designed theoretically. Usually, a method is designed based on other people's work and experimental achievements, as found in the literature. Using the experimental successes of one's own lab and those in the literature, one creatively combines and applies the known possibilities to design an experimental method for the open research question. Personal knowledge of the researcher can function as one of the premises for the design. When the researcher has had some novel experimental successes (or failures), they might design a new experiment based on the success of these new possibilities. Personal knowledge may thus function as an assumption about the practical possibilities in the lab, and in this way guide the design decisions.
3. The experimental phases, Method development and
4. Data creation, are mainly practical phases, where a lot of time is spent in the lab; doing experiments, experimental troubleshooting, and collecting enough data to facilitate sensible conclusions supported by sufficient statistics. Personal knowledge is important in these phases because physical skills are a crucial factor in the success of an experiment. The characteristics of physical skills are discussed, in detail, later in this chapter. Skills are inherently personal, because this knowledge necessarily applies to one's own body and how to use it. Skills are thus personal knowledge, and are required for successful experimental research. Personal knowledge also plays a role in (acute) decision-making during experiments. I analyse this function in points 1, 2, and 5.
5. Data analysis. Data analysis too has both theoretical and practical aspects. One uses a combination of theory, skills, and interpretation, before coming to a conclusion. Known theories are needed to test and explain the data. Skills are needed to use software to carry out computational analyses when required. Interpretation is needed for scientific development, to take a step into the unknown. An interpretation is an explanation of observed phenomena. Interpretations necessarily go beyond the data. They can be based either on theory, or on personal sources. An example of personal knowledge used in data analysis is when personal sources, like experiences, determine which results are to be trusted and which are not. These personal motivations will be called dispositions in this thesis. An interpretation often comes in the form of a hypothesis: a formulation of a possible scientific fact, that is to be found, tested, or verified. In cutting-edge research, hypotheses often go beyond the available theory and data. When contemplating the unknown, the available theory is inherently insufficient as a guideline. Hypotheses are usually based not only on theory, but also on personal disposition. For example, decisions on which data to trust are often based on previous personal experiences. Hypotheses and interpretations of data are equally

dependent on dispositions. Therefore, personal knowledge strongly affects the researcher's interpretation of data, and the creation of hypotheses, which guide scientific decisions.

Personal knowledge manifests itself in two ways in nanobiology. It functions in the form of *physical skills* that scientists need in the lab to perform their experiments. Secondly, personal knowledge functions as motivation for scientific theories and decisions. In decision-making, personal dispositions, for example personal experiences, emotions, or intuition, function as assumptions, or as inspiration for interpretations and hypotheses.

1.2 The role of personal knowledge

In this s chapter I will try to bring to life the above: what kind of experiences, decisions, and skills are at play in the practice of nanobiology? How do these function in the execution of experiments, in the creation of hypotheses, and as guidelines for decisions in scientific dilemmas? I will give some examples of experimental skills and personal dispositions, and how they constitute or affect the scientific activities of a researcher. Chapter *Skills* aims to show how physical skills are crucial for the correct execution of an experiment. Chapter *Dispositions* aims to show how personal knowledge affects scientific decision-making.

The significance of experimental skills

I will discuss two examples, cases of different of physical skills required in experimental nanobiology. The first is a very general skill for any experimental researcher in a field concerning biology or chemistry, and shows how even the most basic aspects of this experimental research are physically challenging. The second example we discuss is a more specialized skill. The example shows how the special circumstances that the samples in nanobiology require can create difficult or challenging conditions for the researcher.

Pipetting

One of the most basic skills in nanobiology, a skill that pervades virtually all biological research, is pipetting. Pipetting is a method that is used in the lab to transport small volumes of liquid, with the order size of millilitres to tenths of microlitres (10–3 to 10–7 litres), from one tube to another. Pipetting nowadays is usually done with a modern, scientific pipet (Figure 1). Using the pipet is probably the most basic physical skill in (nano)biological research. Almost every experiment that involves biological samples contains a substantial amount of pipetting. These experiments will typically start off by making the required, enriched salt solutions that will sustain and protect all biological components needed in the experiment during the measurement. The researcher (after doing some horrifying mol concentration calculations) mixes together the calculated volumes of the designated dilutions, to make these solutions. A pipet is fairly straightforward to use: one adjusts the settings of the pipet to the desired volume (usually a matter of turning a knob), fixes a new pipet tip on the pipet,4 and transports the desired volume from its container into the final solution. Transporting the volume is done by first pressing the knob of the pipet, placing the

[4] This already requires some tacit skills and is a critical part of the pipetting: one must fix a new, clean, pipette tip on the pipet, before every use. This must be done without touching any part of the attachment site of the pipette for the pipette tip or the pipette tip itself, for risk of infecting it with bacteria. It is also crucial that the pipette tip should be perfectly affiliated, in order for the volumes to be correct. After the volume is set and the tip is fixed, the pipette is ready to use.

pipet tip in the liquid, and then releasing it to suck the liquid into the tip. The content of the pipet tip is emptied into the final solution by pressing the knob again. This requires some physical skills, for, despite its apparent simplicity, there are many minor mistakes possible whilst handling the pipet. When one is too quick, momentum in the volume can cause more liquid than the set volume to get into the pipet tip, especially in viscous fluids. Also, bubbles can arise in the tubes or in the tip, that make the pipetted volumes unreliable, or cause damage to the biological system in the sample. Pipetting very slowly is not always a possible solution to avoid these risks, due to numerous logistical constraints. The only realistic way to avoid these complications is to become very accomplished at pipetting. Moreover, pipetting very small volumes, order of 10–1 microlitres, is inherently difficult. It is possible to get too much liquid into the pipet tip by using the pipet button wrongly. In the same way, one can go wrong in emptying the pipet tip of its content. Researchers need training before they are able to use the pipet properly5.

Figure 1 Eppendorf scientific pipet 10 µL

Minor mistakes in pipetting can have significant effects on the samples. The exact size of a pipetted volume can be of great importance and significance to the experiment and its results[6].

Pipetting quality can affect the experiment significantly, even if the concentrations are not critical. The following example is from an experiment that was part of my own research on DNA unwinding in the Nynke Dekker Lab, TU Delft. In this research, we performed an experiment that took around 10 hours, of which 3 to 4 hours required continuous pipetting of small volumes into an inlet tube. The quality of the pipetting was of critical importance for the success of the experiment. Bad pipetting would lead to bubbles, bubbles stick to the surface and the whole experiment would be disqualified. This turned out to be so difficult that, in the end, the experiment never yielded a sufficient amount of useful publishable results. The experiment depended strongly on, and was limited by, the physical skills of the researcher.[7]

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[5] See (298) How to pipette correctly – a short step-by-step introduction into proper pipetting - YouTube.
[6] A small error can cause a large concentration diversion. Many proteins are extremely sensitive to certain concentrations (Okuno et al. 2001; Mishima et al. 2004).
[7] See Gordon et. Al. (2015), and van Loenhout et. Al. (2012) for more information on magnetic tweezers. The importance of pipetting skills is not mentioned in this literature.

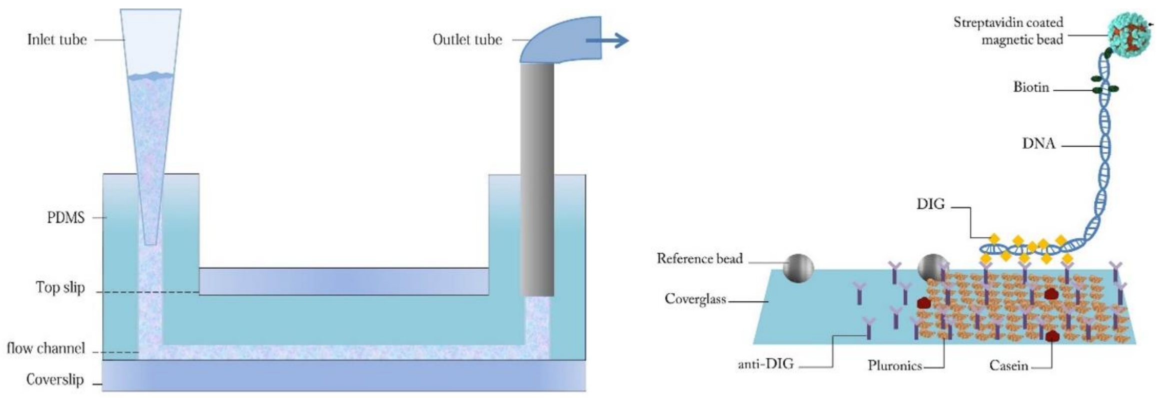

Figure 2. Image on the left: Schematic image flow cell of the DNA unwinding experiment with magnetic tweezers. The inlet tube is used to pipet the desired environmental conditions into the chamber. The outlet tube is connected to a syringe. Image on the right: schematic image of the content of the flow cell. On the bottom there is some surface passivation. A string of double-stranded DNA is tethered to the bottom of the chamber on one side, and to a magnetic bead on the other side.

Glovebox

This is an example of a more specialized physical skill. It exemplifies how the special conditions that are required for an experiment can result in tasks that are physically challenging for the researcher.

In one experiments, some of the experimental steps needed to be executed in an environment without oxygen, because the involved biological materials, in this case lipids (a component constituting cell membranes), are easily degraded through oxidation. Since a human researcher will not be able to survive in such an environment, these experimental steps are executed in a sealed, see-through box, filled with nitrogen, called the glovebox. The sample can enter the glovebox via a lock system; the researcher can enter the glovebox with their hands via large rubber gloves that reach into it, and handle the sample inside the box like that. See Figure 3 for an image of the glovebox being used by an experimentalist.

This experiment required two oils to be mixed with lipids inside the glovebox. This was a matter of opening two vials containing the lipids, setting up a special pipette inside the box, then taking two large cans with special oils and pipetting a certain amount of these oils from the large cans into the small vials. Afterwards, all containers had to be closed, the special pipette dismantled and everything cleaned, all inside the glovebox. Conceptually, these tasks are very simple.

Performing tasks inside the glovebox, however, is physically specialized and complex, due to its special environmental circumstances and some practical limitations. Firstly, the glovebox is under high pressure, which means that it can be very difficult (especially for a lightweight/small person) to get their arms inside. Additionally, it is uncomfortable to have your arms inside the glovebox, as they are being squeezed by the pressure. Secondly, the gloves should be large enough for everyone, which means that, for the average person, they are too big. For a small person, they are much too big. The pressure of the box shapes the gloves randomly and firmly around the users' hands. This effectively results in having very large, irregular shaped hands and fingers, that have no feeling in them. Furthermore, in my case, this glovebox was mainly used to mix lipid oils. As a result, everything inside the glovebox, including the gloves, was oily. This makes refined motor tasks difficult; simple tasks like opening a small vial and putting it down, or setting up a pipette, can become challenging.[8]

Figure 3. Researcher using a glovebox. The sample is inside the box. The person handles the sample in the glovebox by entering the box with their hands via rubber gloves.

In this experiment, the oil mixing step was essential and critical, like most experimental steps in the protocol. If the oil did not have the right composition, it would not function properly. If for example the vial fell over, and the content was spilled, the entire preparation (2 hours) would have to be redone. Or, if the vial fell over while it was already closed, some plastic from its lid would dissolve in the oil, with an unknown effect on the results. Learning how to operate in the glovebox takes some instruction, time, and practice.

Having to operate an oily glovebox, using oversized gloves, is not something that every experimental researcher in nanobiology has to deal with. This example aims to show that the special conditions that these sensitive samples and complex experiments require, can easily lead to difficult experimental circumstances for the researcher, that require specialized physical skills.

Skills in scientific practice

These physical skills are a special kind of knowledge. They are inherently personal, and tacit. They are personal because the knowledge concerns one's body and how to use it. In addition, a physical skill knowledge cannot be explicated, because of the way it is present in our body. There is no way to put this knowledge on paper. We will discuss how and why skills are tacit in detail when we consider contemporary literature on tacit skills in philosophy of science.

The importance of dispositions in scientific decision-making

This paragraph discusses some examples of how personal knowledge influences scientific decision-making through dispositions. The term 'disposition' here is used to indicate any thought, feeling or hypothesis of a scientist, that is not fully supported by objective knowledge and that plays a role to determine their decisions. We define 'disposition' as everything that is not (yet) theory that enables decisions. We aim to show how dispositions are used to decide in scientific dilemmas all the time in scientific practice.

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[8] We discussed before that tacit knowledge is inherently personal because it is about how one uses one's own body. In the glovebox, not only one's manual skills are the subject of the relevant tacit knowledge, but one's entire body. The pressure (=weight) and dimensions of the glovebox relate to the weight and dimensions of the body of the researcher during the experiment. These parameters, the parameters of one's own body (in relation to the parameters of the material) determine how one individual uses the material. Some researchers in the lab were too small to reach the glovebox properly, so they needed to use a stool to be able to get in. The example of the glovebox clearly shows how tacit knowledge is not only dependent on refined manual movements, but can also involve other specifics of one's own body.

In the lab, the different experimental phases, creating data, data analysis and interpretation, formulating a hypothesis, and making a decision, often collapse into one another. Many unknown or unexpected situations arise, in which the researcher has to formulate a hypothesis and make decisions on the spot. The examples that I discuss in this chapter thus do not neatly follow the structure of scientific activities that was given before, in my analysis of personal knowledge in chapter 1.1 The scientific practice of nanobiology. The reader will be able to understand, based on the examples, how these phases all collapse in the experimental context.

Acute decision-making

During experiments in the lab, many things can go wrong, and do go wrong. In unexpected and acute situations, in which the experimentalist has to make a decision quickly and in great uncertainty. Many dilemmas in scientific practice cannot be solved by purely theoretical reasoning and on the basis of objective facts. Sometimes, a personal disposition is needed when the theory is indecisive. This is often the case in a type of situation that I will call 'acute'. 'Acute decision-making' is necessary when something unexpected happens. Everyone might recognize such stressful situations from daily life, for example: do I hurry to catch the train, knowing that I run the risk of forgetting something? Or do I choose not to check whether I locked the doors and windows, to make sure I arrive on time? There is no correct answer, 'the theory is indecisive' in this situation. The 'right' answer completely depends on your priorities and your risk assessment. Once one ends up in this dilemma, one will have to make a decision based on some personal motivation. An acute decision is usually based on some feeling. A few examples from lab dilemmas will now be presented, followed by an explanation and speculation on how the decision might be made:

a. Do I continue with the experiment with an unknown effect, or do I stop the experiment?

In this case, the vial has fallen over and the liquid inside has touched its lid. We know that the chloroform in the lipid oil dissolves plastic of the lid. If the vial has been on its side for a couple of moments, chances are that some of the lid's plastic has dissolved in the oil. The question is whether to cancel the experiment and start again. In this case, a researcher is likely to formulate a hypothesis on what happens in the vial and let that hypothesis determine their decision. This hypothesis might be based on earlier personal experiences, if there are any relevant ones. If the vial had fallen over before, the results of that experiment would probably influence their hypothesis and be decisive in this situation. However, even if the results were good or normal last time, the researcher might still feel uneasy, for example about the fact that any dissolved plastic is affecting the sample in an unknown way. Or, if the previous trial resulted in a failed experiment, they might have the intuition that this was not due to the (possibly) dissolved plastic. It is hard to say what the best decision is The researcher will need some personal disposition to take the plunge. This might be based on empirical observations, conceptual reasoning, or other things.

b. Do I choose to vortex the lipid oils for one minute instead of two, or to have the formin[9] out of the fridge one minute longer?

[9] Formin is a protein that has an important function in synthesizing actin polymers in the cytoskeleton of the mammalian cell.

In this experiment, we do not know the effect of vortex duration, nor the effect of keeping formin out of the fridge. We do have some guidelines for conceptual reasoning. Vortexing separates the lipids in the solution, which will give better results, probably. The protein formin is sensitive, and its fluorescent label is too, so this component might degrade quickly. Thus, the data might become hard to interpret correctly. The researcher has to decide between the risk of degrading the quality or usefulness of the results or decreasing the transparency of the results. Just like in the previous example, personal experiences of the researcher or other, close, researchers in a similar dilemma, might affect the hypotheses on these processes in the mind of the researcher. A similar question is:

c. Do I run back and forth to the freezer to get new actin or do I perform the measurements with half a concentration of actin?[10]

In this situation, the researcher runs out of actin unexpectedly. They can run back and forth to the freezer to get new actin out of the stock. This might degrade the quality of the rest of the sample, since the rest of the proteins were already mixed, and will now start interacting with the formin, and polymerizing. Also, the quality of the actin has been optimal in the previous experiments of the researcher when it had been defrosted slowly, and about two hours ago. However, not adding that additional actin would mean that the concentration of actin is half that of its usual concentration in the previous experiments that this one is trying to repeat. Again, she has to decide between options that have no theoretical preference. This decision is likely to be made based on intuition or personal priorities.

Situations like these arise especially often in nanobiology. Because it is a relatively new scientific field, many effects, mechanisms, and processes are unknown. One has to guess at the significance of an event constantly. A disposition can be the result of other people's advice, an intuition, an earlier experience, and many other things. In the next paragraph, I will discuss at how personal experiences can function as an assumption.

Design decisions & Trouble shooting

In design decisions and experimental troubleshooting, there is often such a high number of parameters, that it is impossible to check every single one. Instead, when something is not working, many things in the design are adjusted simultaneously. Choosing which parameters to check for abnormalities, which parameters to adjust first, and which parameters to consider as less significant, or less likely to cause the problem, is a matter of personal dispositions. Often, these choices are based on people's gut feeling and/or previous experiences. The following examples aim to show how scientists base their design decisions on personal dispositions.

d. Is it better to keep the temperature of this protein solution low, or to keep it constant?

In this experiment, we know that both temperature changes and the freezing and thawing of protein solutions can degrade the quality of the protein. We also know that this protein degrades quite fast at room temperature. The only tool we have for keeping a solution at a low temperature whilst carrying it around in the lab (from one room to another), is the icebox: a styrofoam container filled with ice. Should we keep this solution on ice during the preparations for the experiments, whilst constantly taking it out and putting it back in? We know that such an event as taking it out and putting it back in will have a significant effect on

[10] Actin is another protein, the main protein constituting the cytoskeleton.

the temperature of such a small volume, only 5 microlitres. There is no way of knowing in advance. And it is very time-consuming to perform multiple experiments to test this effect. The gut feeling of the researcher might be that its effect won't be significant enough to make the effort of spending four experiments (at least a full week) checking it. So, she will just use her intuition to decide on this, or her experience with previous protocols, or similar cases from the literature.

e. Should we perform the experiment in the cold room, knowing that it is very humid in there, risking the degradation of the lipids?

In this experiment, cell-like compartments, made from lipid membranes, were created to encapsulate protein solutions. The protein solutions contained a composition of proteins that interacted with each other. It was known that this interaction disturbed the formation of these cell-like compartments. It was also known, from literature, that a lower temperature would significantly decrease the activity of these proteins. Thus, encapsulation would probably be optimal when conducted at only a few degrees Celsius. However, the only way to practically execute this plan was to perform the encapsulation of the protein solution into the lipid membranes in the 'cold room'. The cold room is kept at 4 degrees Celsius, but it is humid inside. It is also known that lipids are very sensitive to humidity. And it was also observed in the lab that this experiment was highly sensitive to humidity too. The researchers cannot know in advance what has a stronger effect.[11] It is likely that this decision would be based on either the experience of the researcher with humid days, or based on some literature that they might come across on the effect of either temperature or humidity on similar experimental protocols.

f. What is the best way to clean this component?

Surface passivation and cleaning protocols are extremely important for successful experiments and very hard to design theoretically. The development of the cleaning or surface passivation protocol is usually a very intuitive, process, containing lots of trial, error, advice, and long shots.

The role of dispositions in the practice of scientific dilemma's

We see that the decisions the scientists have to make in these cases are all similar to each other. The only difference between acute decision-making and design decisions is that there is slightly more time to reflect on design decisions. There is more time to reflect on some hypotheses, but time remains limited. There is not enough time to check the effect of every single action, parameter, or deviation. If the effect of every second of vortexing, every concentration in the passivation treatment of the glass surface in the sample chamber, should be tested, and the experiment cancelled every time the researcher made an unexpected error, we would never have any scientific results. It is not an option for the experimentalist to wait until they make no mistakes during the experiment to finish it or to use the results. It is also not an option to wait until all effects or the significance of every parameter are known. That

[11] In this case, performing the experiment was tried only when the experiment did not work at all. It worked; the results were excellent. Performing the experiment in the cold room was given up as a standard, because of the practical complications it brought. Probably, this result has never been published and this knowledge, that we can consider to be the personal knowledge of a handful of researchers at the Gijsje Koenderink Lab, will perish.

day will not come. Therefore, decisions in these 'practical situations', where theory falls short, are often based on personal dispositions[12].

Purposefully, I do not differentiate between personal experiences, hunches, intuitions, emotions, etc., when considering personal dispositions. These could originate in previous observations, or in other's previous observations, and could be the result of intuition, gut feeling, conceptual reasoning[13], or something else. Even if it is theoretically possible to make these distinctions, it would be difficult for a scientist to do so on the spot, and impossible to do so every time. I therefore think that it is unrealistic – either completely impossible, or practically unrealistic and counterproductive – to make such a distinction. One does not know what exactly constitutes their disposition. I think that it is unrealistic to make any distinctions between different kinds of dispositions, reliably. All dispositions feel the same: a disposition that one has 'theoretically justified' or has acquired through 'intuition' or based on a previous 'observation', they can all be equally strong feelings of seeing the truth. Before we find out which intuitions turn out to be true and which turn out to contradict the observations, it is hard to say which ones are 'conceptual' or 'theoretically justified'. We will discuss this some more when we consider the literature on emotion in scientific decision-making.

1.3 The functions of personal knowledge in scientific practice of nanobiology

We have identified two functions of personal knowledge in the scientific practice of nanobiology. The first is handling one's own body and samples with skills, the second is making decisions using dispositions. From the examples a–c, we have seen that tacit skills are crucial for the success of experiments. Skills are inherently personal. It applies to how one handles the sample with one's own body. Furthermore, it is hard or impossible to translate into words. From the examples d–f, we have seen that scientific dilemmas are often solved using a personal disposition. The dispositions are personal knowledge, because their source or justification is personal, accessible for the individual only. Both types of personal knowledge are scientifically relevant. The way they function affects the scientific practice and the results significantly. I conclude that personal knowledge plays an important role in the scientific practice of a researcher in nanobiology. We will proceed by discussing the philosophical implications of this according to contemporary literature on personal knowledge in philosophy of science.

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[12] One could argue against the examples given above that they concern only tiny scientific steps and activities. The examples discuss mainly single experiments. I would argue in response that in fact there exists nothing empirical, besides single experiments all added up. All single experiments together are one hundred percent of the experimental data we have. Furthermore, some experiments, especially new ones, are not easily put into statistics or reproduced. The personal disposition of a scientist during one experiment and the interpretation of its results can be significant in the development of cutting-edge experimental research.

[13] With reasoning, I mean that the scientists formulate a hypothesis, based on better- or lesser-known principles, that might or might not apply to the case in question (see the example b above about vortexing). The reasoning is conceptual; however, it does depend on the interpretation of the researcher. For example, whether this principle does in fact apply to the given situation, or whether its effect is significant, is a matter of personal assessment of the researcher, not a matter of theoretical fact. 'Conceptual' insights are often still very personal, they are accessible to the individual only, and also possibly difficult to get across.

2. Philosophical analysis of personal knowledge in the scientific practice

2.1 Personal knowledge in philosophy of science

The types of personal knowledge that we have discussed, skills and dispositions, are usually tacit. This means that they are not easily put into words. It is not easy to put into words how exactly to handle a pipet properly, and even more difficult to put into words how to perform refined motor tasks in a glovebox, with oily, oversized gloves. Some philosophers think that it is impossible to put tacit skills into words. In philosophy of science, this is often seen as a problem. Tacit knowledge is considered to be a mysterious, or unreliable, or inferior kind of knowledge, because it cannot be explicated, or translated into propositions. In this chapter, I will discuss two contemporary philosophers of science, H. M. Collins (1974, 1985, 2010) and Brandon Boesch (2019), who are concerned with tacit knowledge. They argue for the acceptance of tacit skill knowledge in (philosophy of) science. Dispositions are explicated even less in the discourse of natural science. Dispositions are not only hard to explicate, they are not accepted as scientific knowledge or as part of valid, scientific reasoning. The role of emotion and intuition in scientific reasoning is often completely ignored. I will discuss a contemporary philosopher, James McAllister, who has tried to argue for the acceptance of emotions based on previous experiences in scientific decision making. In McAllister's (2014) theory, emotions are defined as personal inclinations towards presented material as a result of personal experiences.

In my discussion of the two philosophical views, I start by giving an overview of concepts and arguments that in contemporary philosophy that relate to the phenomena I have discussed before. I give my own evaluation of the philosophical problems, arguments and conclusions proposed in these literature. Finally, I draw a conclusion on the remaining philosophical problems regarding personal knowledge in nanobiology.

Tacit knowledge

Some knowledge is not or cannot be put into words

In the introduction to the book, *Tacit and Explicit Knowledge*, Collins (2010) defines tacit knowledge and discusses its essence. Collins defines tacit knowledge as knowledge that is not explicated. The aim of his book is to dissolve the mystery often surrounding tacit knowledge. It has been a confusing subject, Collins claims, because of the tension between 'is not' and 'cannot', with regard to the (possibility of) expression of tacit knowledge. The book aims to take that tension away.

According to Collins, it is a misunderstanding that anything that cannot be expressed is weird or mysterious. People wonder: how can we have knowledge that we cannot express? But in fact, it is not mysterious at all. Collins encourages the reader to consider the fact that there have been tens of millions of years where nothing was really expressed. Thus, Collins rejects the common philosophical treatment of tacit knowledge as hard to understand or mysterious. It might be hard to fully describe tacit knowledge, but so is almost everything. The body is quite central to knowledge for everyone. This is not a feature of knowledge itself, but rather of how people generally acquire knowledge. A body provides the conceptual structure of our lives, but it does so in a collective/societal context. According to Collins, the collective and societal aspects of knowledge are more important for our understanding of knowledge than the embodied factors of knowledge are. Opposed to tacit knowledge, explicit knowledge can be translated into, and transferred via, 'strings': signs, patterns, anything that can be transmitted via a screen. To clarify knowledge with regard to these themes, Collins defines three modes of tacit knowledge: weak tacit knowledge, somatic tacit knowledge and strong tacit knowledge, which I will discuss here.

Weak tacit knowledge, discussed in chapter 4 of *Tacit and Explicit Knowledge*, is knowledge that is tacit because it is not explicated for relational reasons or for reasons of economy: time, energy, interest, etc. Relational contexts can make the explication of certain things redundant, or, reversely, it can be the case that one is not aware of the needs of the other. And sometimes it would be possible but very impractical to explicate the tacit knowledge that is at play, because it would, for example, take a long time. An important reason that some knowledge is tacit is that it 'cannot' be explicated for logistical reasons like these. An extreme example that Collins uses to make this point clear is the following: we know how to build a rocket that can accelerate a human to 280,000 kilometres per second, and we know that such a device will not need more resources than there are in the universe. However, it would require such an inconceivable amount of resources that we cannot imagine actually building it. This is one of the factors that causes tacit knowledge to be tacit in Collins definition, meaning, not explicit.

Somatic tacit knowledge is tacit because of the way it is inscribed in the material of our body and brain. Somatic tacit knowledge could be expressed theoretically but not practically. In the following passage, Collins's view of somatic tacit knowledge is clearly formulated:

> We ask the standard question once more: can all somatic tacit knowledge be made explicit? The answer is "yes," if here "explicit" means "expressed scientific understanding of causal sequences. Somatic tacit knowledge is just causal sequences and in principle, if not in practice, these can be understood scientifically. We can foresee how we might go about it though it remains technically beyond our capacity. The answer is also a qualified "yes" if we are talking of explicable knowledge (in sense 3)—the ability to reproduce the uses of the knowledge in machines. The limits are not limits of principle or ability to foresee how to do it; they are limits of practical ability, the affordance of different materials, and engineering considerations of that kind. In sum, there is nothing philosophically profound about Somatic tacit knowledge, and its appearance of mystery is present only because of the tension of the tacit with the explicit: if we did not feel pulled toward trying to say what we do, and if we did not make the mistake of thinking this is central to the understanding of knowledge, we would find nothing strange about our brains' and bodies' abilities to do the things we call tacit. .... And that is why too much concentration on the body as the seat of the tacit takes one away from a proper understanding of the idea. (Collins 2010, p. 117)

Somatic tacit knowledge is not transferred via strings, because it would be very impractical to do so. Somatic tacit knowledge involves training our muscles, hand–eye coordination, and other motor skills. It does not easily allow for sensible explication. But if we wanted to, we could translate tacit knowledge into strings, for example by programming a robot to perform the same tasks.

And finally, in chapter 6 of *Tacit and Explicit Knowledge*, Collins discusses strong tacit knowledge. It is defined as knowledge that a person can acquire only by being part of a society. An example that Collins provides is natural language. Collins mentions the modes of teaching that are associated with this inexplicable category of knowledge: "demonstration, guided instruction, and personal contact" with others who have the desired ability. In chapter 7, he discusses an example from his own research showing that technicians are able to learn how to build a laser only via these modes, and that they failed to learn it by studying texts (Collins 1974, 1975). The chapter proceeds to discuss the effect of string length and context on knowledge transfer in these cases.

The problem with tacit knowledge

Collins raises the philosophical question of what makes tacit knowledge tacit and how we should feel about that. Collins thinks that tacit knowledge is not mysterious or philosophically interesting because it is tacit. All weak and somatic tacit knowledge could be made explicit, or programmed into a machine. What is philosophically interesting about tacit knowledge, according to Collins, is that it is relational and societal. I agree with his analysis of the different reasons that cause knowledge to be tacit. At first thought, tacit knowledge that is used in the lab is mainly weak and somatic. It is not explicated because that would take too many words, time and effort. Another reason is that it is difficult to explicate physical skills: they are not 'in propositions', but in the body and motor part of the brain. Some of these physical skills might be translatable into words. It would be possible for sure to program a robot to perform the tasks that we described. However, Collins's own research into the skill of building a laser already suggests that tacit skills used in the lab might be different. In that case study, everyone who tried setting up the laser using only instructions via 'strings' failed. An example from my own experience is the use of a high-end microscope and its software. One would think that it is possible to write down the *entire* instruction for handling such a microscope. This is in fact done. However, it is not possible transfer the ability to use it properly. When a new person needs to learn how to use the high-end microscope, he or she usually has to go through hours of guided instructions. Only people who are already highly experienced at using these types of microscopes read the manual. So a manual does not serve the purpose of transmitting an ability to someone who does not yet have it, or its basics. In other words, it is not possible to explicate this skill in a way that will actually make it available, openly, explicitly, to anyone interested.

This border between what is explicated, what can be explicated in strings, what can be programmed, and what can be learned only in a society, is always moving. We do not know whether it is theoretically impossible for computers to learn natural language. We are already able to program computers in a way that their information processing and learning is similar to ours (neural networks). For this thesis, it is not relevant whether we could theoretically transfer the knowledge by strings, or whether it would theoretically be possible to program a robot. We are interested in the best way to conduct science, and the best way to deal with the personal aspect of tacit skills. With regard to this, it is clear from Collins's own research that tacit knowledge is best transferred by demonstration, guided instructions and personal contact between teacher and student.

I thus agree with Collins that many important parts of scientific knowledge, like skills, are tacit. They cannot, or not realistically, be put into words. I agree with Collins too on his main point: tacit knowledge is not scary or mysterious. Collins thinks we should take tacit knowledge seriously in science, and so do I. The problem that remains after establishing that some knowledge is tacit, is how we should deal with tacit knowledge in practice. If the knowledge is tacit, it can thus not be transmitted via *strings*; no publication will suffice.

I will proceed with discussing a contemporary philosophical view concerned with the transmission of tacit knowledge and skills. Boesch (2019) puts a lot of emphasis on the philosophical importance of teaching tacit knowledge. I shall again start with a short overview of the philosophical view put forward by Boesch and others, and continue with an evaluation of this theory.

The philosophical relevance of skill transmittance

Boesch bases his work on that of Collins and Evans on the role of tacit skills. Boesch focusses on 'contributory expertise', defined as the expertise that someone has when they are capable of making a scientific contribution to their discipline.

In the introduction to "Skill Transmittance in Science Education: Studying the Skills of Scientific Expertise", Boesch (2019) rejects the view that tacit knowledge, knowledge that is not expressed or explicated, is not a possible or possibly interesting subject of study. Boesch is going to show we can in fact study tacit knowledge and get to know things about it; we cannot explicate the skills, but we can access, explore and understand them. One way in which we can access them is via skill acquisition and transmission, a context of research in which these skills are exemplified.

Boesch explains the general structure of the philosophical debate about tacit skills. On the nature of know-how, usually the debate is between two accounts: the intellectualist and the anti-intellectualist accounts of tacit knowledge. The intellectualist account holds that skills are a subspecies of propositional knowledge[14]. The famous example in traditional discussions about tacit knowledge, is about Hannah knowing how to ride a bike (see Polanyi, 1958 Stanley, 2001; Collins, 2010). Stanley's view is that Hannah knows how to ride a bicycle, so, it must be the case that Hannah knows that *w* is a way to ride a bicycle. The anti-intellectualists account of tacit knowledge holds that tacit knowledge is a different kind of knowledge, that need only show itself, and not be expressed. However, there is also a third option. Will Small (2014) has an account that rejects both. According to Small, both accounts do injustice to tacit knowledge, because both forget about the fact that it can be *transmitted*.

As Small put it, we are in need of an account of skills that begins with "what was plain to the ancients, and is plain to us in ordinary life—namely that skill is a form of knowledge that can be transmitted, and that its transmission takes place through teaching and learning" (Small 2014, p. 88). Small suggests that we can find just such an account in the work of Aristotle. Central to Aristotle's understanding of the nature of skills is the case of joint exercise

[14] One example of a philosophical work endorsing this view can be found in Stanley and Williamson (2001).

of a skill between a teacher and learner, e.g., when a student pianist plays a song in front of her piano teacher (Small 2014, p. 99). Aristotle thought that there was a meaningful sense in which the cause of the student's piano-playing was the teacher's skill. The Aristotelian view is that a skill has a life cycle, which includes practicing, expertise, and teaching. Investigation of a skill is thus not complete if we study only the expertise phase. This insight also gives us the opportunity to study a tacit skill in one phase, for example the teaching phase. Studying the transmission of a skill will yield insight into the skill itself; however, it will be incomplete if we are not able to access it in another phase.

The practical problem of tacit skill transmission

Boesch raises the philosophical question whether and how we can access tacit knowledge if it cannot be explicated. Boesch agrees with Small and Aristotle that tacit skills have a life cycle, and it is during the transmission of tacit skills from teacher to student that tacit skills are somewhat explicated and that we can access them. I agree with Boesch's analysis that the transmission of tacit knowledge is philosophically relevant and interesting. The transmission is the phase where knowledge that is usually not explicated finds its way from one person to another.

Tacit knowledge needs to be transferred because it is scientifically relevant. This is often difficult and demanding. We will see clearly later that it is exactly this phase, the transmission of tacit skills (personal knowledge), that is problematic.

The status of emotions in philosophy of science

In the paper "Methodological Dilemmas and Emotion in Science", McAllister (2014) analyses scientific dilemmas and how scientists deal with them. McAllister studies multiple cases from the practice of natural science. As McAllister observes, there are often inconsistencies, incompatibilities between results or between methodological precepts. He focusses on the methodological dilemmas, which arise because of conflicting scientific values. McAllister shows that scientific values, generally pursued by philosophers of science as well as scientists, are numerous, practically independent and without hierarchy. This causes dilemmas: cases of conflicting obligations to perform incompatible actions. How do scientists solve these dilemmas?

At the end of section 4 (p. 3148), McAllister suggests that it is by using emotional responses that scientists are able to decide and act in these situations. Scientists use emotional responses to assesses the acceptability of hypotheses and the trustworthiness of empirical data. Emotional responses are defined a positive or negative affect. He formulates his twofold argument as follows: Firstly, Antonio Damasio's research (1994, 1999) has shown that people with an impaired emotional system have an impaired ability to for practical reasoning. Practical situations are defined as a situation with many unknowns and insecurities, where one cannot make a choice using a schematical, complete method. Rather, reasoning in these situations is forced to be selective and incomplete. The emotional appears to enable the subject to set goals, or priorities, and identify salient features of the situation. In addition, McAllister explains that the most important scientific decisions that scientists are faced with, are in fact decisions that require practical reasoning, in which emotion plays an important cognitive role. McAllister gives some examples of scientists testifying the emotional motivation for their choices. He concludes firstly that it is the case that scientists rely partly on emotion in making decisions of certain kinds, and secondly, that it would be impractical or even impossible for scientists not to do so.

McAllister then asks if and how emotional motivations for decisions can be rationally warranted in science. Rational warrant of a procedure is defined in his paper as

> if the fact that a conclusion was reached by this procedure constitutes, under certain conditions, grounds for believing the conclusion to be justified. For example, use of induction is warranted if the fact that an inference was reached by induction constitutes, under certain conditions, grounds for believing the inference to be justified. (McAllister (2014, p. 3154)

According to McAllister, the fact that a decision is based on emotion can in fact be a reason to believe the conclusion. It is clear from his examples that the emotional responses that scientists experience are not easily traced. By this I mean that scientists can only report to have a *feeling* on what a law of physics *should* look like. (It should be symmetrical, or elegant, for example.) This is because, he theorizes, emotions are created inductively. They are based on previous experiences of successful and unsuccessful science. Therefore, emotional responses are a detector for desirable features of scientific products, like empirical data and hypotheses.[15] This is a generalisation of the theory of aesthetic induction (McAllister, 2014). Aesthetic induction is the creation of (aesthetic) norms for scientific products, by induction, based on previous experiences with successful and unsuccessful scientific products. This theory preserves the empirical justification for scientific decisions based on emotions, without the need for scientists to be able to point to a particular piece of empirical evidence or justification. Scientists can therefor trust their feelings, without having to know exactly what caused it, because we know that it is based on a principle that has been created empirically and inductively.

The status of dispositions as a motivation for scientific decisions

I agree with McAllister's analysis that scientific decision making is practical. Most decisions are infused with uncertainties and unknowns. Before discussing McAllister, we were already aware of the fact that scientific decisions cannot be based on theory only, because theory is inherently insufficient when studying the unknown. Based on Damasio's research and McAllister's analysis, we now know that scientists require their emotional system, before they are able to make these practical, scientific decisions.

According to McAllister's aesthetic induction theory, emotional responses provide feedback on the presented scientific product, based on inductively created aesthetic norms. Defending any theory on the origin of emotions, however, lies outside the scope of these thesis. I have difficulty with adopting any claim on the origin of emotions. I do not feel entitled to make any statement on how emotional responses are created; whether it is through aesthetic induction, as a reaction to coherence in all our interpretations that are stored in our subconscious (Thagard, 2002), or in any other way. There might be such feedback

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[15] This theory is alternative to the theory of Thagard (2002), who has a coherence theory of emotions in science. According to him, emotions are rationally warranted because they are a detector of coherence. McAllister's advantage is that aesthetic induction applies to the scientific content, not only to the formal form of the scientific products.

mechanisms that create emotional responses. However, I think that there are many more types of dispositions, next to these *emotions*. There is also gut feeling, intuition, hope, trust in what someone else said, interpretation, conceptual reasoning, etc. All these 'mechanisms' create dispositions. As I stated before in section 1: The role of dispositions in the practice of scientific dilemma's, I think that scientists are not able to tell them apart, and certainly not in the moment. I will use the term dispositions, to indicate every inclination that a scientist might have, that is not purely theoretical, or logically based on objective facts.

McAllisters question is how emotions could be acceptable as a scientific motivation; the theory answers what requirements they need to for fill: they need to be based, inductively, on empirical evidence. I think that the fact that our emotional system is necessary in practical situations is enough of a requirement. I thus also think that to ask what kind of entity emotional responses are (empirical, coherence-detecting, rational, irrational) is not the question we should be asking. The question, for me, is: how should scientists deal with them and the way they affect their scientific decisions.

Philosophical question regarding dispositions in this thesis

My philosophical problem is the following: many scientific decisions are not isolated, and neither are scientists. A scientist and their projects are usually part of a group of scientists working on a larger scientific programme, all doing related research. Because of this social structure of science, a scientist often has to justify and communicate their decisions to other scientists. Not only is justification of decisions needed in the context of one's own research group; this is demanded also in the larger context of science: in publications and at conferences the communication of justification plays an important role. Effectively, all scientific decisions one makes need to be justified to others. Emotions and other dispositions are not accepted as a justification in the scientific, and if they would be, scientists would still have a hard time transferring them on paper.

In conclusion, I am convinced that scientists need their emotional responses in order to act in scientific dilemmas. I have seen and experienced this myself in the lab, I have heard my fellow researchers admit this, I have seen the convincing examples of great scientists that McAllister has given (2014), and I believe we can conclude this based on a more objective proof, as provided by McAllister and Damasio. However, I do not want to make any claims on the origin of dispositions, as I think this is beyond my abilities. The problem that remains is: if dispositions are not rationally warranted themselves, or I do not want to defend that, how can we accept their role in scientific practice? Why should we accept subjective knowledge? One thing that is very clear from the contemporary philosophy of science is that dispositions are in need of an explicit scientific justification. I will address this problem in the next chapter. Furthermore, if we accept the role of dispositions in scientific decision making, how can we transfer these scientifically valid modes of reasoning and justification, when then are personal and tacit? I will address this problem in chapter 4.

2.2 Philosophical problems concerning personal knowledge in nanobiology in this thesis

We have seen that personal knowledge is scientifically relevant in nanobiology, as it manifests in skills and dispositions. I discussed these two functions first by using examples, to clarify their role. Then I proceeded with a philosophical analysis of these functions. I already added a short evaluation of my own view in the discussion of contemporary literature (Collins, 2010; Boesch, 2019; McAllister, 2014). In this section, I will give my perspective on the goals and methods of natural science. From this, I formulate the general problem concerning personal knowledge in natural science. In addition, I discuss some examples to show how this manifests itself in the practice. This section ends with a conclusion on the two remaining problems, and a formulation of the corresponding research questions that I will answer in the following two chapters.

Transmission of personal knowledge

In the examples we will emphasize how both personal dispositions and skills are not always recognized for what they are, and subsequently transferred with difficulty.

Transmission of skills

Experimental protocols are usually written down. They contain a list of all actions that one should execute in order to perform a certain experiment. These lists are treated as objective knowledge or as 'objectively' transferrable. In scientific papers, the method section often has only a couple of hundred words. The word limit on the method section that is imposed by the publisher is often disproportional with the time, effort and significance of the method development. This suggests that it is not regarded as a scientifically relevant information by the scientific authorities. Method sections are sometimes vague and abstract also because of purposeful secrecy. Even on a small or personal scale, like that of a single lab, transmission of tacit skills can be lost because of failed communication or assessment of the essence of these skills. When we regard the scientific significance of the method and its difficulties, we conclude that it would be reasonable if this information was treated as equally important to the research as the results.

I have experienced similar situations in my own research group. A former PhD student had accomplished successful actin encapsulation using the cDICE method.[16] It was captured on paper, but there was no one left in the lab who had learned how to perform this experiment. When I arrived, another PhD student had managed to reproduce some of their more basic results, by using a reconstruction of their experimental method. It took a couple of years to get the experiment back to work. This PhD student made sure to pass on the knowledge in person, to me and others. This took multiple sessions of guided instruction, which comes down to multiple days of intensive supervision.

At one stage, I was the only one who could perform a certain experiment, because I had created it. It was a couple of months after I had learned the cDICE protocol, when I created an alternation that we called eDICE. At first, I tried to transfer this new knowledge by written instruction and schematic drawings, but this failed as a means of enabling others to perform the experiment. No other scientists in the lab could get the experiment to yield results based on these instructions,. It took me multiple weeks to transfer this skill to the other researchers in the lab. The fact that the protocol was written down and videotaped was still useful, as this secured documentation and completeness. We know that written instructions are useful for people who are already skilled in a task. And some objective

[16] Continuous Droplet Interface Crossing Encapsulation. See: Abkarian, M., Loiseau, E., & Massiera, G. (2011).

account of the protocol is definitely useful. However, the most important factor for transferring this skill was, in my experience, demonstration, guided instruction, and thus days of accompaniment. I found out myself how hard it is to transfer skills to another person.

Scientists in my lab agreed that it might be possible to write down protocols. There was one PhD student who was responsible for the supervision of at least five bachelor's and master's students. She had to teach these students how to use the microscope, for example. If she wrote instructions down, she tried to put on paper instructions as if she were standing right next to the reader. She tried to explain everything she did when using the microscope herself. "It should feel like I am in the room with them." For relatively user-friendly microscopes and students with some experience this mode of instruction had a chance of succeeding. This chance was increased were someone present in the lab to whom the student could go if they had a question. For more complicated and expensive microscopes, instructions are usually similar to the intensive supervision that was used in the above examples to transfer the skills needed to perform a new experiment.

In our department, instructions on the use of the microscope was a case of successful skills transmission. Because the microscope was so expensive, and so many people depended on it, the responsible person would give every new user personal training. This training consisted of three sessions. The first was an instruction, where the student was supposed to observe and take notes. The second session was a guided instruction, where the student was supposed to execute some tasks under supervision. The third session was performing all tasks without instruction and minimal guidance. When taken as seriously as this, the transmission of a skill like this went very well.

Because writing down a protocol does not work properly for transferring a skill, experimental protocols are now sometimes captured on video. On an online platform, scientists can find filmed instructions for different experimental protocols. Scientists in my lab found this a good development. Unfortunately, the videotaped instructions did not always work. One researcher in my lab told me that one of the reasons they did not always work for him was because of the editing of the videos. When videos are edited, one do not know what happens in between the cuts. He explained that the big difference with respect to witnessing the experiment in real life, was that he afterwards felt as if he had done the experiment before, and believed that he could do it himself. When one is present when the experiment is conducted, one can be sure that it is possible, and that one knows how. Being present gives the student a feeling of having done it before, and thus of being able to do it.

Transmission of dispositions

In communication, scientists often try to back up their opinions with theory. Some personal dispositions are used in their reasoning, they will all admit. But, in the interviews that I conducted, it came out they often reflect on this as a necessary evil. They would like to do everything 'correctly', use only objective and theoretical knowledge. But the situations and experiments are too complex, it is not possible to check everything. Of course it is possible to find out many things. Most experimental steps have been done before, and there is a lot in literature to find out about them. They usually try, and everything they cannot explain or they have to fill in, they will portray as a logical inference. Even when some conceptual principles are known, it still takes a personal disposition to create the hypothesis that one believes. McAllister's work indicates that, in philosophy of science, many do not approve of emotional justification of scientific decisions. The communication and justification conveyed by many scientists, suggests that view is shared in science too.

A lot of the processes and methods one uses for experimental tasks in the lab is based on how people around them do it. Taking advice from a researcher around you who has run into many similar problems, and solved them, can save you a lot of time and energy.

When a researcher simply has had the experience that causes a disposition it might be transferred to their peers in the lab. For example, my PhD supervisor told me tricks like: after spinning down the actin (something one does this, in preparation of an experiment that needs actin), check whether there is a sediment in the tube. If there is, I have always found that the actin is usually amiss. Furthermore, you will find a small pallet of actin floating around the tube. When pipetting out the actin, try to avoid that actin, it is probably aggregated polymers of actin that turned bad after freezing. This kind of practical know-how is often transferred to closely related scientists. But dispositions are sometimes also shared with people from another lab or research group. Even though some groups are secretive about their methods on purpose, many groups also cooperate to develop and improve their methods and results. In my research group, we cooperated with two other groups in the same department, who were working with the same methods. Every now and then we would have a meeting on our progress with the method. We would share passivation techniques, cleaning protocols, how long to vortex the lipid oils, what humidity to aim for in the microscope room, etc. The dispositions that were shared were usually based on specific personal experiences that the individual could still remember.

Trust is an important factor in the transmission of information and knowledge. Regardless of whether personal dispositions are explicit in scientific communication, most scientists take them into account when judging presented information. Everyone knows that one's scientific reporting is highly dependent on personal dispositions. Because all researchers know that this knowledge is highly dependent on the individual transferring it, it is also judged as a personal matter. The people I worked with were usually respectful towards authorities; anyone who was a professor or group leader was usually trusted. If there is not a status that secures someone's credibility, it is judged based on personal factors. One would judge the credibility of another based on how well they can identify with the other researcher, for example. People from my lab explained that they trusted another when they knew that the other person had been through the same experiences in the lab. Or, one would trust someone when they knew their style of working was similar to their own.

Not only in meetings; even when considering the publications of other labs, trust can have a significant effect on how researchers take what is presented. Trust in the content of a publication can be influenced by the author and their status too, of course. When the author is unknown to the reader, degree of identification can again play an important role. Researchers from my lab explained that what they needed before they trusted another scientist or research group, was transparency and the feeling that they understood the decisions and claims of the other, or would have acted, judged or interpreted in the same way.

Thus, I conclude that dispositions are often not transmitted explicitly. They are present in the reporting and work of all scientists, though in implicit form. Their (implicit) presence is taken into account by other scientists in how they trust one's work and reporting. As disposition can be felt through one's account, although this is sometimes with difficulty.

When scientists know each other, they usually get a feeling for the other's implicit dispositions. When they do not, they judge whether they can distil them and agree with them. This is usually easier once the dispositions are more explicit. From what I have seen, transparency usually had a positive effect on how much one scientist trusted the reporting of another.

Formulation of my philosophical problems

We see that both types of personal knowledge that we have discussed, deal with the same problem. This problem is twofold: firstly, I have suggested that personal knowledge is often not taken to be scientific knowledge. Therefore, it is not properly acknowledged, and its role is sometimes disregarded. Secondly, if personal knowledge is accepted, and considered scientifically relevant, it needs to be transferred. This can be difficult because the knowledge and its source or justification is only accessible for the person holding this personal knowledge in question. Furthermore, the personal knowledge that we have discussed, skills and dispositions, is often either difficult or impossible to put into words. In this paragraph, I will give my philosophical analysis of these problems and why they are a problem. Finally, we will formulate the two questions that we will answer in the remaining chapters.

Goal of natural science

Why is personal knowledge not recognized as scientific knowledge, even by scientists who admit to use dispositions in their scientific activities all the time? Natural science studies objects and materials that we suppose behave in the same way in equal conditions everywhere. The experiment that is performed in the lab in Delft should under perfectly equal conditions yield the same (with statistical variance included) results, when performed in Los Angeles. This is important not only philosophically and theoretically, but also practically. We want to use the products of nanobiology to apply in, for example, targeted drug transportation inside the human body. Therefore, the knowledge that we produce should be applicable anywhere. We want to create objective, general knowledge, that is useful for all applications and circumstances, independent of the individual person, specific lab, or particular machine. The main problem regarding personal knowledge in natural science is what I will call its locality.

Communication in natural science

Natural science is concerned with objective facts, and communication methods are optimized for transferring objective and theoretical knowledge. We write protocols and papers. We try to describe our actions, reasonings, and observations separately from the context, the individual, or any personal aspects. Writing a paper, however, is not a suitable way to transfer skills or dispositions. Tacit skills are often not translatable into words, because of the way they are wired in our body and brain. Dispositions too are only accessible to the individual. Most often they are also difficult to explicate any more precisely than as positive or negative. I believe that one is not even able to tell what caused their disposition. When we conclude that personal knowledge is essential scientific knowledge, the question remains: how can we transfer personal knowledge?

2.3 The remaining questions about personal knowledge in nanobiology

Personal knowledge plays an important role in the practice of nanobiology. This is often ignored or hidden, because it is not acknowledged as scientific knowledge. Furthermore, scientists have a hard time transferring personal knowledge.

First of all, it is the question whether and how personal knowledge can be scientific. I already showed that personal knowledge is scientifically significant. But we can still question whether that is actually philosophically possible or right, and how. Furthermore, we have seen that the personal and emotional aspects of decisions are usually hidden and ignored. Is that how it should be? How should we consider personal knowledge in science from a philosophy of science viewpoint? The first research question that I will try to answer in the remainder of this thesis is: how can personal knowledge be scientific knowledge in natural science, that is concerned with creating objective knowledge?

If we can establish the scientific status of personal knowledge, a second problem arises about how to deal with personal knowledge in scientific practice. Personal knowledge is difficult to transfer because it is *personal*. It depends on one's body, on one's experiences, and on one's emotions. It is information that is accessible only to the individual. The second research question is: how can one transfer personal knowledge to another, when it is accessible only to them and hard to put into words?

3. A feminist philosophy of science

In this chapter, I construct the philosophical perspective based on which I will evaluate and compose judgements about values, norms, and practices in natural science. Against the expectations some have when encountering ‘feminist theory’, it will not be used to discuss gender in this thesis. The terms masculine and feminine refer to a set of values and methods in both science and society that have traditionally been associated with femininity and masculinity, or their discourses. Restoring the perspective, from a masculine to a neutral one, means that we reflect on the way science is constructed and evaluate all possible scientific values and their scientific relevance, without (gendered) bias. We consider feminist philosophy of science as the answer to the question raised in the previous chapter: How can personal knowledge be scientific knowledge in natural science?

3.1 Restoring the perspective

The effect of gendered bias in society on (scientific) values

In the introduction to *Reflections on Gender and Science*, Keller wrote:

> scientists who are "driven to escape from personal existence to the world of objective observing and understanding" (Einstein, quoted in Holton 1974, p. 69) actively embrace—even choose—a picture of reality as being "as impersonal and free of human values as the rules of arithmetic"; that scientists, as human actors, find some pictures or theories more persuasive and even more self-evident than others in part because of the conformation of those pictures or theories to their prior emotional commitments, expectations, and desires." (Keller 1995, p. 10)

Science and the scientific method have proven to be extremely successful, Keller asserts. In this important work in philosophy of science, she asks: what can the natural sciences gain by becoming feminist? Or, what can a feminist philosophy of science mean for natural sciences, considering their success without it?

Keller (1995) shows in part 1 of *Reflections on Gender and Science* how gender and gendered concepts have shaped our intellectual tradition and that this has affected our philosophy of knowledge and of science. Masculine methods have become the norm, whilst feminine methods and values have been excluded from science. An example of this is the use of emotions. She also considers the fact that our intellectual tradition has gone through many changes in the past. Values and methods have always changed in both philosophy and science. The creation of knowledge and our approach to it have changed significantly over time.[17] In part 2 (Keller, 1995) thoroughly discusses the philosophical consequences of changes in science and reflects on the consequences of the differing valuation between femininity and masculinity in society and its effect on science. The fact that we no longer generally endorse sexist values, and that we know that we can change our scientific values, results in the question: how should we decide our contemporary scientific norms and values?

[17] A discussion of whether change is improvement or whether improvement is even possible in science is outside the scope of this thesis. For this thesis I will generally hold the view that *as long as we use roughly the same concepts, we are improving, building, and advancing technology and increasing control, manipulation over things that matter to us.*

The need for a re-evaluation of scientific values

After studying Keller, one is aware of the importance of gender dichotomy in the construction of our intellectual tradition. This has resulted in a skewed distribution of values in science, where feminine values have been excluded. However, according to Keller (1995), this happened without proper justification. Keller (1995) argues that we must take into account the effect of factors that seem to be non-scientific, like politics, social dynamics and relations, on our norms and values in science. Feminine methods have been excluded from science because of a skewed valuation of femininity and masculinity in society (Keller, 1995; Anderson, 1995; Richardson, 2010; Crasnow, 2013), not because of their scientific relevance or worth. We should reconsider the worth of these practices, methods, values, because they have been excluded for the wrong reasons. I, too, adopt the view that all methods and values deserve a fair chance as being of possible worth in scientific application. This is a motivation for me to study and develop new scientific methods and assess their possible worth and applications in this thesis.

Finally, Keller makes the convincing claim that, by excluding factors and influences that are inherently present in human conduct from science, we do not free science of these influences, we let science be a victim of them. This is what happens with subjectivity, Keller emphasizes. I will discuss this theme in great detail in section 2.2, later in this chapter.

The values that we endorse

Elisabeth Anderson has been a major scholar in feminist philosophy of science, for example with her work on epistemic justice (2012), objectivity in feminist epistemology (1995), and feminist philosophy of science (1995). In the book, Feminist Epistemology: An Interpretation and a Defense (Anderson, 1995), the problem of feminism in philosophy of science is defined as follows: feminine values and methods have been ranked as inferior to masculine values and methods, and this affects the methods as well as the subjects, questions, and products of science.18 Anderson's feminist epistemology aims to investigate the assumptions and values that we have unconsciously accepted in our perspective on knowledge, and evaluate them. Like Keller, she has come to the conclusion that 'feminine' methods, like emotions, relations, context, intuition, and values, like personal and practical, have epistemic relevance too: in natural science, we always need more than merely empirical evidence to create general theories. Theories inherently go beyond the observable or empirical facts. These 'other' things might be emotions or values. They might even be sexist values, although it would be irrational to implement sexist values when we do not explicitly endorse them. With regard to the relevance of gender, Anderson clarifies that the 'traditional feminine values' she mentions, are not actual characteristics of women (Anderson, 1995; Keller, 1995). These values are just labelled like that. Men and women can conduct both types of methods and honour all types of values. Ideas about hierarchy in types of knowledge and methods can both shape and distort the interpretation of information. This can be acceptable to a certain extent, because theory is always a distortion of the data. But it is important that we make explicit the values that dictate the way in which the data is distorted, and that we truly endorse these values.

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[18] My phrasing

The personal experiences and dispositions in life affect the way we see even objective facts. Anderson discusses known cases in primatology to exemplify that. Primatology is the scientific study of primates. It is a study focusing on living objects, with subjective experiences, like emotion etc. However, as long as the researchers do not interact with the primates and do not influence them, their behaviour is an objective fact. The interpretation of their behaviour nevertheless can vary greatly. This can be explained as a result of differing disposition in researchers. The same thing can happen in any science. What one sees can be affected by one's focus on certain phenomena, what one has learned to value, and what methods one has been taught to use in observation. Indeed, these personal aspects might be an effect of our broader scientific norms. If we value numbers more than we value structures, our science will focus on counting, not touching. This does not mean that feeling is a less effective method. It is a very effective method for certain purposes, like determining structure. However, it is less efficient for determining quantity. Furthermore, numbers and counting do not inherently carry more value for science: their scientific value exists only because scientists assign them. This can happen for multiple reasons, scientific usefulness and societal reputation being two of them.

Finally, Keller (1995) adds, following Quine: there is no clear boundary between natural science and social science, analytic and synthetic truths, personal and impersonal, rational and irrational. The claim that physics is purely theoretical is not true, as I have argued throughout this thesis. Even in physics, there is the effect of the observer on the observed. This could occur through communication or through personal experience. We might be able to use non-theoretical knowledge in theoretical reasoning and science, as we might use personal knowledge in biophysics. (This is an input/process difference: Smith 1974.)

For me, it is clear that feminine and masculine values do not in fact correspond with characteristics of human genders. I have shown why we need to re-evaluate the possible roles of methods and values that have been excluded from science for the wrong reasons. Values are up to discussion; we are able to define them, they are subjective to what matters to us. Values are not defined by science: science is defined by them. We have to choose them in a way that aligns with our interest, needs, and desires. This argument motivates us to re-evaluate the importance of certain values in response to changing morals or interests. It is a justification to (re)evaluate the role and scientific significance of personal knowledge and subjectivity in nanobiology. And this will also be a justification to consider the relevance of relations, social dynamics, and communication related methods, like empathy, in the context of nanobiology.

I will proceed with an in-depth discussion of the tension between subjectivity and objectivity, using the work of Donna Haraway (1988) and Sebastian Rödl (2017).

3.2 Objectivity and subjectivity

The subjectivity of what we know

Donna Haraway's work, "Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective" (1988), focuses on the dependence of objectivity on subjectivity. According to Haraway (1988), objectivity is a critical attitude *from* a well-known, explicitly taken *position* of the knower, and additionally the resulting responsibility of that position.

Haraway discusses the role of one's own subjective position with respect to objective knowledge. The paper (1988) is an abstract and complex one (in my opinion). I try to summarize Haraway's (1988) point as follows: Knowing or knowledge is not without body, without a position, from a God's-eye point of view. Instead, knowing entails that one has a position from which one knows. Knowledge that is a-positional is empty because it is trivial. True objectivity therefore means taking a critical stance from a position. Haraway uses a metaphor of seeing that is meant to signify knowing in general: seeing is not objective, seeing can only be done with a system that interprets and selects. 'Objective' seeing does not mean seeing without a body or position, because seeing does not exist at all in that way. Objectively seeing means to have awareness of the position from which you see, taking responsibility for it and being critical of it.[19]

"Situated knowledges" is a famous text; however, it can be hard to understand what the concrete meaning or application of her view is, since she uses numerous analogies and is abstract in reasoning throughout the text. I will therefore consider Sebastian Rödl's work in addition. My interpretations of Haraway (1988) and Rödl (2017) are comparable positions. I argue that understanding Rödl's argument will help with the understanding of Haraway's theory.

Imperfect and dependent knowledge

Sebastian Rödl is an analytic philosopher who proceeds from the epistemology of Kant and Heidegger. He discusses the role of the personal position, or 'situatedness', in attaining objective knowledge. Rödl and Haraway seem to agree, coming from different perspectives. I will discuss Rödl as complementary to Haraway, before drawing my own conclusion.

In "Finite Knowledge" (2017), Rödl argues against the sceptic, that knowledge, *human* knowledge, is situated, imperfect, and dependent on induction/general laws. He makes a distinction between 'finite' and 'infinite' knowledge, which corresponds to the distinction between human and divine knowledge. Divine knowledge is metaphysically infinite, which means that it is independent, self-containing, and perfect. Divine knowledge is its own ground. It is absolutely certain, without the possibility of being wrong. Human knowledge is dependent, it is situated, it is metaphysically finite.[20] This means that it is not complete in itself, but must be based and dependent on other things or grounds. Divine knowledge is a completely different thing, so we should not measure our way of knowing to divine knowledge (Rödl, 2017).[21]

Rödl (2017) argues that, because divine knowledge is independent and a-situational, its subject is so too. Divine knowledge contains only purely general truths. Human knowledge, however, is about a human experience, about our world. It is inherently

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[19] This text might be a critique of the idea that knowledge can only be acquired by the 'disembodied genius', as described by Steve Shapin in (1998).

[20] Moore, in "Infinity", explains the distinction between metaphysical finitude and infinitude as the difference between being dependent on other things, entities and circumstances, like human beings, and being complete, independent and self-containing, like God. [Please put this reference in the bibliography as usual.]

[21] This means that when we are discussing human knowledge, we are not lowering the bar of knowledge on a scale from divine to human, because this scale containing both human and divine knowledge does not exist. Human and divine knowledge are two completely separate concepts, not different grades of accomplishment on the same scale. We are not concerned with divine knowledge: we are assessing what human knowledge is.

situational and dependent; so is our world, so is our knowledge. Everything we experience is dependent on certain conditions, the context, and our own abilities. Human knowledge is an interplay between laws and particular facts. One can know the particular from the general, and also induct the general from particulars. This is valid reasoning and justification that leads to human, dependent, incomplete knowledge that is subject to error.

Rödl (2017) makes a convincing argument that it is impossible to exclude the personal and the subjective from our knowledge. Complemented by Haraway (1988), he makes clear that the only way to escape purely situational knowledge, is not to exclude or ignore the situational factors – to try and get divine knowledge/a god's-eye perspective – but to embrace it, explicate it, and be critical about it. Both authors emphasize that we need the subjective to attain objective knowledge; attaining objective knowledge is acquiring knowledge of many particular cases and taking a critical position towards the subjective aspects of that knowledge. Before we can do that, we need to embrace subjective and situational aspects of that knowledge. We run the risk of making knowledge *more* subjective if we ignore subjective and situational aspects and thereby do not allow a critical attitude.

Subjectivity and personal knowledge in natural science and objective knowledge

If human knowledge is situated, and the personal position from which one knows is a crucial aspect of that knowledge, then it is also scientifically relevant what the position is from which one knows. We should thus acknowledge situational and personal knowledge not only as a part of knowledge, but as a part of scientific knowledge as well. Consider this example: if we do not take it as an aspect of our medical knowledge that our hypotheses, in this case the effect of a certain medicine, have been tested only on male patients, or people with a white skin, then our science becomes a victim of situational aspects. Our 'objective' knowledge, in which the situational aspects were not critically considered, is now subjective knowledge, dependent on contextual factors. Similarly, scientific knowledge can become a victim of personal factors in nanobiology. For example, an experiment might be implicitly dependent on the knowledge that I have on how I can make a certain sample, using my body, and the material in my lab. This knowledge is inherently situational, and that kind of knowledge will always be personal and situational. This is a reason to study those personal factors as equal parts of our knowledge and evaluate their position in our scientific knowledge.

Remember the question that was posed with regard to personal knowledge in natural science: Does personal knowledge have a function in creating objective, scientific knowledge? This question depends on a more practical concern: What do we ultimately want to achieve with this science, what is its goal?

In this thesis, I consider science to be the joined effort of creating knowledge. This is not just any knowledge: science is the effort of creating knowledge consciously. The scientific practice is concerned specifically with creating knowledge that has not yet been created, replicated, and published before. That's different from most modes of acquiring knowledge. Most of the knowledge that one has is trivial: where your tea mug is for example. And most of the knowledge that people have is personal, or local. Natural science is the conscious creation of novel, nontrivial, general knowledge: it studies phenomena that are universal, and produces principles that reach beyond individual facts. It has the implication, expectation, purpose, premise, and promise to be about everyone, or about everything; we want the scientific results to be applicable on a much broader context than where they were created.

What do we want to do with vesicles that can encapsulate proteins?[22] We want to use them as medicine transport, we want to use them for all kinds of synthetic cell research, for biomechanics research, etc. So, we prefer to create as broad, as generic a piece of knowledge of as possible about vesicles, in order for that knowledge to enable us to use it for all possible purposes. We prefer to gain a-situational knowledge about making these vesicles, in such a way that we can make and use them anywhere in the world, under all circumstances. That is the problem we have with situational knowledge in natural science, it is subjective, whilst the knowledge that we aim for is objective.

However, we have now been able to realise that personal knowledge is scientific knowledge. All scientific knowledge starts out as personal knowledge: knowledge that is accessible only to one individual, one scientist. At the start, knowledge depends on this person completely, and on the very specific conditions of this lab, material or skill. We could even say that all empirical knowledge is personal. All observations and the reports of these observations have been taken by a person and depend on that person. In order for us to transform these situated knowledges into law-like, general knowledge, that goes beyond the individual facts, we have to know the subjectivity that is contained in it. Furthermore, we have seen in the previous chapter that knowledge or hypotheses that go beyond the facts, also require personal input: I called these personal inputs dispositions, whereas McAllister (2014, 2005) called them emotions.

To the question of how personal knowledge can be scientifically relevant to natural science, aiming to produce general, law-like knowledge, we can now reply that creating a-situational knowledge, for a human being, means that one considers one's personal situation critically (as emphasized by Haraway (1988) and Rödl (2017)). Objectivity is the critical approach to your own position from which you know. Generic knowledge (about vesicles and how to make them anywhere in the world) means that we know what our position is as knower, what our situation is, what our knowledge depends on. Not that we put ourselves outside a situation or a dependency. This requires all the insights about how your knowledge is situational. Therefore, situational knowledge is scientific knowledge. All scientific knowledge that goes beyond the facts, contains personal dispositions, as we have seen in chapter 2. Philosophers and scientists should accept that empirical knowledge is situational, and acknowledge and evaluate the subjectivity that is contained inside it; the dispositions should not be ignored or hidden. That is how we create objective, law-like, general knowledge. Objective knowledge is insight into one's position. To acquire objective knowledge, one has to embrace the subjective, and be critical of it. Then it is possible to assess the effect of the situational factors and to use induction to create knowledge that applies to all situations, 'objective knowledge'. A-situational, empirical, knowledge does not exist. This is a justification for this project, for the attention we pay to the subjective, personal, private, practical things in scientific acting and reasoning.

[22] Vesicles are small, cell-like compartments, that can encapsulate a protein solution. Research on how to encapsulate certain proteins in these vesicles are used for synthetic cell research and medical research on drugs transportation in humans.

3.3 A feminist philosophy of science framework to accept the scientific relevance of personal knowledge

The basis of our framework defined at the beginning of this chapter gives us a reason to consider personal knowledge as a potential significant contributor to scientific knowledge, even though it does not meet traditional scientific standards or values. I concluded that we may evaluate or reconsider all methods and values as possibly scientifically relevant (Keller and Anderson). Thereafter, I examined the philosophical discussion of the role of personal and subjective knowledge in natural science. A feminist philosophy of science offers us a framework in which personal knowledge is essential in our quest for objective knowledge. Thus, there is an important reason and justification to study and honour the personal aspects of knowledge that nanobiologists use in the context of scientific research. I concluded that personal knowledge and subjectivity also play a role in creating general, objective knowledge. In this philosophical framework, it is crucial to acknowledge subjectivity and the personal aspects of our knowledge. To create objective knowledge, we should be critical of our own position, subjectivity, and personal dispositions.

To create scientific knowledge, we want the knowledge to be transferred, conveyed to the rest of the world, accessible and applicable everywhere. We conclude that personal knowledge, tacit skills and dispositions, are scientifically relevant, *because* we need the subjective before we can reach objectivity, and we need to acknowledge what is subjective in order to attain objectivity. The next question is: how do we transfer the subjectivity that is contained inside our knowledge? If these subjective elements are tacit skills, and personal dispositions, like emotions and intuitions, how do we get them across, to be accessible for others?[23] We have already observed that it is often no good to try and put tacit skill knowledge into words. Additionally, any human being knows how difficult it is to put emotional motivations in to coherent phasing. In the next chapter, we consider this problem: How can we transmit personal knowledge, from one person to another, in natural science?

[23] Of course, one can be critical of their own subjectivity in one's own knowledge. However, this won't cure the knowledge of personal factors completely. We need repetition, reproduction of results, many observing eyes and interpreting minds to do the trick, usually.

4. The role of empathy

The goal of this chapter is to answer the second research question posed at the end of section 2: How can we transfer personal knowledge in science? In this chapter, I will consider the role and potential of empathy in transferring personal knowledge.

First, we need a working definition of empathy: an account of the experience and effect of empathy. I will discuss three different philosophical stances with regard to empathy and evaluate them briefly. I then take the work of Edith Stein as a basis for my philosophical view on empathy, augmented with the view of contemporary philosophers of science concerned with empathy in science. After the working definition of empathy is established, I proceed by discussing its role in nanobiology.

Empathy for objects

Some contemporary philosophers have been concerned with empathy for objects, instead of empathy for people (Currie, 2011). I consider empathy applied only to living creatures, especially humans. In this thesis, I will not be concerned with empathy for objects.

4.1 What is empathy?

Empathy can be used to refer to a wide range of character traits or capacities that play a role in human interaction, caregiving and morality. The definition of empathy can vary greatly, inside, as well as outside philosophy. One of the essential and most characteristic aspects of a definition of empathy is the perspective it assigns to an empathic feeling or act. Empathy can be seen as a first-, second- or third-person act. I will discuss the different perspectives in the next paragraphs.

First-person perspective empathy

A first-person perspective definition of empathy holds that empathy is a feeling or experience that one feels or has, as one's own feeling, and that corresponds to the felt experience of the other. The perspective taken by the empathizer is self-oriented. This view on empathy is a traditional one, endorsed by for example Lipps (1903), who was one of the first to use the word Einfühlung in philosophy (translated as "empathy"), as a means to access the other's mental state. First-person empathy can be accomplished by putting yourself in the other's shoes, and image how they are feeling. In the literature we find many similar definitions and phrasing, for example 'empathy through mimicking' (Lipps, 1903), 'empathy through similarity' (Leake, 2012), or 'empathy through affective matching' (Coplan, 2011). Empathy as a first-person experience might thus be seen as the product of a thought experiment. Or it is seen as the effect of mirroring others' expressions. In a first-person perspective definition of empathy, one is able to attain the felt experience of the other by these or other methods. An important consequence of a first-person perspective definition of empathy is that, when this kind of empathy is accomplished, there is no distinction between the felt experience of the one empathizing and the one empathized with. The second consequence is that empathy is effected by the imaginary power of the person trying to attain it, and the extent to which this person and the person they are empathizing with are alike. These consequences are usual targets for critique and disagreement. An account that claims the attainment of an identical felt experience seems problematic. It is hard to believe that one can attain a truly identical experience to that of the other by means of mimicking and projection in thought. The most pregnant problem with using these methods to accomplish first-person perspective empathy, is that the empathizer is a person different from the one she empathizes with; merely putting yourself in the other's shoes will not suffice (Coplan, 2011; Leake, 2012).

Debes (2010) aims his critique at the philosophical interpretation of recent discoveries of 'mirror neurons' as a proof of the first-person perspective definition of empathy. Debes emphasizes, in addition, how the first-person perspective definition of empathy lacks the facet of *understanding* as a philosophical account of empathy. There is increasing empirical evidence for the existence of 'mirroring neurons' (Gallese et al., 1996; Rizzolatti et al., 1996; Rizzolatti et al., 2001). 'Mirroring neurons' are observed to be active during the performance of certain actions, as well as the mere observations of these same actions. These mirror neurons also create equivalent activity with respect to observing and feeling emotions. As Debes observes (2010, p. 220): "These discoveries have provoked wide endorsement of the following claim: Plausibly, the way we understand a great variety of observed actions, somatic sensations, and emotions is via a kind of direct representation of those actions, sensations, and emotions".[24] Debes is sceptical about the effectiveness of mirroring neurons as a means of grasping the other's experience meaningfully, and rejects the conclusion that these mirroring neurons are responsible for empathy. According to him, empathy possesses an 'excusing' effect: when empathy is successful, one understands the other in such a way that one excuses the other for their feelings. Debes (2010) describes this as vindicating intelligibility, which is the result of empathy. In other words, he retorts that empathy should be understood as creating a high level of understanding for the other, a kind of understanding that leaves one with the idea that the other is right in feeling that way. After achieving empathy, one might even think that they would have felt the same, being in the other's situation. Empathy yields a justification for emotion itself.

The above contains convincing arguments against the idea that one could, through any method, attain the identical felt experience of the other. Furthermore, it seems wrong to ignore the role or ontology of the other in a definition of empathy (Leake 2021, p. 244; Coplan, 2011, section 1.1).

Third-person perspective on empathy

The third-person perspective definition of empathy regards empathy as the recognition or acknowledgment of a certain feeling or emotion in the other. According to this view, a successful case of empathy would be a situation in which one recognizes that the other is angry. In this definition, the observer is able to recognize a feeling of the target, but is incapable of experiencing, or not required to experience, that feeling any further, any more deeply, or in a more intimate way. A third-person empathic act thus includes neither 'putting oneself in the other's shoe', nor affective matching (see for example Davis, 1996). Few influential philosophers hold this view nowadays, because it seems to ignore or reject the level at which people can feel for or with each other. When someone holding this view does acknowledge that empathy of a higher level is possible, they fail to make a distinction between significant divergence in perceptions of the other mind (Coplan, 2011, p.7).

Although simplicity of a theory can be valuable, the third-person perspective is an insufficient explanation of the phenomenon of empathy. The notion that we are only able to

[24] One of the philosophers endorsing such an interpretation is Iacoboni, 2009.

merely recognize a feeling or experience of the other comes across as uninteresting, hardly feasible, and very much in violation of our own experiences with close or intimate contact.

Second-person perspective on empathy

The second-person perspective on empathy is a more modern notion of empathy, in which both self and other play a significant role in an act of empathy. This can be realized by seeing empathy as relation-dependent or, in one way or another, a shared feeling between two or more people. In this definition of empathy there is always a self/other distinction which is preserved, coexisting with a shared aspect in the feeling or experience (Coplan, 2011; Leake, 2021). Because it both preserves the distinction between self and other and, at the same time, honours the shared faculty of an empathic act, I argue it is the most complete and most appealing empathy perspective.

The second-person perspective definition of empathy has been discussed comprehensively by Edith Stein in her work, "On the Problem of Empathy", first published in 1917, later translated into English by her brother, Waulrut Stein (Stein et al. 1964). Stein was a student of Lipps, and opposed Lipps's argument from analogy as a solution to the problem of intersubjectivity or the problem of how one can access other minds. Stein argued that both self and other are preserved during empathy. Firstly, I will describe Edith Stein's analysis of empathy. This is followed by an interpretation and a more applied and concrete discussion on the second-person perspective.

Stein's empathy: Experiencing the foreign experience

In this paragraph, I discuss the second-person perspective definition of empathy as put forward by Stein in 'On the Problem of Empathy' (1964). Stein starts out by asserting: everyone is a conscious being, an I, experiencing their own thoughts and foreign objects that are being presented to her.[25] According to Stein, empathy is possible through the awareness that other beings are also conscious, experiencing I's. Empathy is what can follow from this awareness: it is the experience of a foreign experience. When one empathizes with another, one is aware of the fact that there is another conscious, foreign, experiencing I. Subsequently, one accomplishes in the act of experiencing the foreign experience. An empathized experience is not primordial,[26] but is led by another experience, which is primordial. The empathizing 'I' is thus able to experience the feeling of the other, although not as a primordial feeling. For example: one feels the joy the other experiences in telling a story. This is not her own primordial joy, however, even though she feels led by the primordial joy of the other.

Stein explains how empathy is distinct from sympathy in this respect. Sympathy is when one I has the same feeling towards an object or event as another I, and they can then sympathize with each other, primordially feeling the same thing about the same object. For example, one can experience primordial joy from the facts that are being presented in the story, just like the other experiences joy from these facts. In this case, both experience primordial joy from the same facts. They sympathize, but need not be accomplished in the act of empathy.

In considering empathy as an *act* of awareness, immersion and understanding of the foreign experience, it is implied that an active attitude is necessary to accomplish this

[25] This is the phenomenological starting point.

[26] Primordial can best be interpreted as a synonym for original.

act. One has to go along with the foreign experience, consciously not letting primordial input dominate one's experience. It is important that I apply some nuance. It will take some people more conscious effort to follow a foreign experience than others. This is also endorsed by Stein (1964, pp. 6-8). A skilled empathizer might empathize effortlessly or automatically. This talent or trained skill affects the degree of empathy. The degree of accomplishment can be affected by training. Sometimes, the amount of knowledge of the other's character limits the degree of empathy.

The key aspect that I will take from Stein's work and use for this project is the awareness of other conscious, experiencing beings and their experiences, which are distinct from one's own consciousness and experience. The aspect of awareness of other conscious 'I's will help extend the point of the importance of personal experiences and human traits in the practice of nanobiology[27].

Aspects of empathy

Amy Coplan (2011) writes about Edith Stein's work in "Empathy: Philosophical and Psychological Perspectives". I will use Coplan's work to clarify the concept of empathy posed by Stein and make her definition more concrete. In the introduction, Goldie (2011) describes Stein's definition of empathy as a unique mode of consciousness through which we directly experience other's thoughts, emotions, and desires.[28] Coplan too considers empathy as something that enables us to experience others as 'minded'.[29] Furthermore, Coplan agrees it is important that there is no loss of self during the act of empathy. This opposes the first-person perspective empathy view of Lipps (1907). In chapter 1, Coplan formulates clear necessary and sufficient conditions for second-person perspective on empathy.

Coplan defines an act of empathy as an act with three essential features: (1) *affective matching*, (2) *self/other differentiation*, and (3) *other-oriented perspective taking* (Coplan, 2011, p. 6). *Affective matching* means that the feeling or experience of the observer is of the same quality as that of the target.[30] Affective matching corresponds to what Stein describes as experiencing the foreign experience. In Stein's account, however, affective matching happens primarily *during* the emphasized experience, and as a non-primordial feeling. *Self-other differentiation* is important, according to both Coplan and Stein, because it ensures that there are still boundaries between the observer and the target. Stein emphasizes this self/other distinction by calling the experience of the observer non-primordial, and the experience of the target primordial.[31] It is this point that strongly goes against the common definition of empathy as provided by Lipps. *Other-oriented* perspective taking is used to indicate the departure from self-oriented perspective taking. It refers to the distinction between imagining oneself in the situation of the other and imagining the *other* in the situation of the other. According to Coplan (2011), empathy can be achieved only when we try to imagine what it is like for the other to be in that situation, not when we try to imagine what

[27] The distinction between empathy and sympathy can help to clarify and highlight this key aspect of empathy.
[28] My phrasing.
[29] This corresponds to what Stein refers to as the experience of the other 'I' as experiencing being.
[30] This is thus already an explicit rejection of the third-person perspective on empathy.
[31] Furthermore, the self/other distinction is apparent in Stein's definition of sympathy.

it would feel like for ourselves.[32] Stein, however, does not consider empathy to be the result of any thought experiment at all. According to her, it is the state of consciousness open to the other that provides empathy. For Stein, Coplan's features (2) and (3) collapse into one and the same thing when she says that one experiences primordially the non-primordial experience. The description of an act where one experiences primordially the non-primordial experience, essentially fulfils both (3) other-oriented perspective taking and (2) self-other distinction.[33] Stein and Coplan thus agree on the aspects of an empathic act: one feels the experience of the other, as the other's experience.

In my opinion, the self/other distinction is necessary for a feasible definition of empathy. As I argued before, I consider it highly unlikely that one would ever attain someone else's experience as their own. For the application of empathy that I suggest later in this thesis, it is sufficient, and crucial, that empathy allows one to access the experience or feelings of the other. This means that one can access the other's feelings, but without implying sympathy: a shared and identical primordial disposition. A definition of empathy containing this feature could be considered as a method to gain knowledge on the other's dispositions. For my purposes, it does not matter whether empathy is regarded as the result of either a thought experiment (Coplan) or a state of consciousness (Stein).[34]

Empathy is a two-way interaction

In this paragraph, I discuss Darwall (2006), who argues that empathy between two people goes both ways. Darwall considers empathy with regard to relational interaction and explains how that applies to daily situations.

Darwall introduces the concept of second-personal reasons in 'The Second-Person Standpoint' (2006). Darwall (2006) claims that many, or maybe even all, uses of language in communication have a second-personal aspect to it, for example because many forms of addressing have built-in presuppositions of authority and accountability. A second-personal aspect arises when the people interacting presuppose authority and accountability to one

[32] Coplan uses a simple example that makes her point quite clear: A, who is an extrovert, has a conversation with B, who is an introvert. A tells B that she has been by herself a lot lately. If B puts herself in the shoes of A, she might fail to achieve empathy, as B likes to be by herself all the time. B needs to imagine what it is like for A to get an understanding of how A must be feeling. She admits that to achieve empathy you might need to know the other person quite well.

[33] The difference is mainly in their philosophical approach, and possibly their context is a contributing factor to their differences. In her work, 'On the Problem of Empathy', Stein is writing a PhD thesis in phenomenological philosophy. Coplan, on the other hand, in the book, *Empathy: Philosophical and Psychological Perspectives*, in the chapter, 'Understanding Empathy', addresses the current questions and debates on empathy, including not only phenomenological philosophy, but also clinical psychology, developmental and social psychology, care ethics, and contemporary cognitive neuroscience. As a result, Coplan is more concerned with empirical evidence and concrete examples, as mentioned before. Stein is not concerned with evidence from natural sciences for her definition of empathy. (A conscious state that allows for the direct experience of another, foreign, experience, of another I.) In addition, when Stein wrote her PhD thesis in the 1910s, the current debates on empathy suffered considerably less from neurological influences.

[34] Although it runs the risk of becoming an almost mystical concept, the description of empathy as the awareness of another experiencing 'I' is more appealing to me than the description of empathy as a thought experiment involving other-oriented perspective taking. I think empathy is not merely a thought experiment, but rather, as Stein puts it, a state of mind in which one is conscious that the other is also an experiencing 'I'.

another. Many types of interactions depend on the presupposition of these relational authority and accountability presuppositions. In interactions such as requests, claims, reproaches, complaints, demands, promises, contracts, these presuppositions result in second-personal reasons. These are reasons that are created and depended on one's acknowledgement of the other's authority to ask something of them or their own accountability with regard to the others' situation. For example, in requests, it is relevant that one acknowledges that the other has the right to ask something of one, or that one is accountable for something the other is entitled to.

Second-personal aspects are fundamentally agent-relative. This second-person standpoint is radically different from a first-person perspective in the way that it entails a relation between two people. The second-person perspective is very similar or equivalent to the first-person perspective in the pure (sensation of) experience. It is different because the first-person perspective lacks an addressing, second-personal aspect that contains the relation and interaction between people. This is expressed in the last paragraphs of chapter 1 (Darwall, 2006). Here, Darwall explains that what makes the second-person perspective different from the first, is the element of a relationship in it: authority and accountability have relevance when it comes to acting in relation to each other. Empathy as a shared experience, with "we" as a subject, captures this process of continuous feedback in communication at its essence effectively and with simplicity.

This reiterative and relational aspect of empathy is very important as all interactions are inherently relational, and thus interdependent, to some extent. The aspect of addressing will be important in this thesis, because I think that the *narrator*[35] is often required to allow for empathy, before the other can succeed in an empathic act. As I will argue later in this chapter with some examples. I will consider the implications of the two-way aspect of empathy in the context of scientists and their communication.

Final working definition of empathy

We need a formulation of the definition of empathy, before I can assess its current and potential role in nanobiology. What is needed is an account of empathy that enables us to recognize empathy and allows us to predict its effects.

My working definition of empathy will be one that regards empathy as a second-person perspective experience, in which one is able to access the feelings, or experience, or dispositions of the other. During empathy, one does not experience an identity between them and the other, but rather focuses intensely on the experience of the other, whilst staying aware of the distinction between self and other. Empathy can be attained through multiple methods. One can either be in a state of active, conscious awareness of the other's experience, or one can immerse in a thought experience in which they take a second-person perspective (Stein, 1964; Coplan, 2011). By accessing the experience and feeling or disposition of another experience, one is likely to gain understanding and of them (Debes, 2010). Finally, I acknowledge that empathy is a two-way *interaction* (Darwall, 2006). Before one is able to immerse in an empathic act with the experience of the other, the other needs to share their experience in a way that allows one to do so.

[35] The person sharing an experience that another wants to empathize with.

4.2 Role of empathy in nanobiology

Now that there is a definition of empathy, I can proceed by assessing its role in nanobiology. Before I start with this analysis on the practice of nanobiology, I want to formulate some requirements for my conclusion in advance.

Virtue ethics in science

In "The Relational Responsibilities of Scientists", Bezuidenhout (2017) discusses what we know about the relevance of communication in science and what we should do with that knowledge. It is relevant for our question of the role and significance of empathy, and what the philosophical consequences of our conclusion will be.

Bezuidenhout explains that it has long been proven that science has a strong social component, yet, she reflects, there is a lot of discussion about the communication between individuals in the scientific practice. According to Bezuidenhout, the difficulty of discussing this social component and being clear about it, lies in the fact that it is extremely contextual and personal, and that the activity or result could have patronizing effects. However, there is a philosophical way to discuss the relevance of communication between individuals.

Virtue ethics offers a path, approach, and framework in which we could do this. Maintaining a virtue ethics in science means that something, a method or value for example, is virtuous if we know that it brings about the best science.[36] Bezuidenhout already proposes one virtue with regard to relational responsibilities: the balance between the social aspects and the individual aspects of a scientist's practice is formed by the virtue of 'practical wisdom'. Using this approach and framework, empathy can become a virtue, which the scientist has the responsibility to pursue, when we have concluded that it facilitates or brings about the best science.

In this section, I consider empathy as a possible solution to the problem of transmission of personal knowledge. First, I discuss the potential of empathy like it was defined, theoretically. Then, I consider the current role of empathy in the practice and how a wider implementation of empathy could improve nanobiology. In order to do this, I reconsider some of the previously discussed examples and add some new examples from my own and others' experiences. I compare cases of successful and unsuccessful transmission of personal knowledge, to assess the role of empathy therein. My examples will serve to make plausible that when transmission of personal knowledge happens successfully, it is done via a method we can now recognize as empathy.

Theoretical potential of empathy

Theoretically, empathy could be a good way to transfer personal knowledge. First, empathy allows one to live the experience of the other. This allows someone to experience what it is like to perform an action, an experiment for example. Tacit skills could be passed on from one scientist to another in this way. In addition, an empathic act is accompanied by affective

[36] For this approach to really succeed as a framework for philosophy of science, a good framework of virtue ethics in science must be built, according to Bezuidenhout (2017). I think that we have already established in chapter 3, I formulated the philosophical framework for this thesis. I stated that values can be acceptable in science because all personal disposition can be acceptable in science. Personal dispositions are not only used but also necessary for the creation of knowledge. We should accept dispositions, like values, as drivers for scientific acting, as long as we are explicit about them and actually endorse them.

matching. In other words, through empathy one can access the dispositions of the other. Thus, an empathic act can facilitate the transfer of a disposition from one scientist to another. By applying empathy, a scientist is, in theory, able to transfer both types of tacit, personal knowledge that I discussed, skills and dispositions. Empathy is potentially a method for transition of personal, tacit knowledge, because of its features *other-oriented perspective taking* and *affective matching*.

Since tacit knowledge cannot be passed on through words, it must be passed on in a different way. There is no explicit method for this in nanobiology yet. I suggest that empathy is possibly a good method for this37. With regard to the passing on of personal and tacit knowledge, such as skills and dispositions, we can imagine that it is difficult to convey on paper, because the skills and dispositions themselves cannot easily be put into words. Like we have seen in Collins' (2010) work. However, human-to-human communication must include more than just words to facilitate the transfer of tacit knowledge. If the transmission is to be done through empathy, the narrator must facilitate empathy and the recipient must be actively, empathically involved. Both sides must cooperate with empathy before it can take place.

If empathy is the/a method through which tacit, personal knowledge can be transferred, then we should be able to see the following effects: 1. If empathic action is taken, tacit knowledge is successfully transferred38. 2. If empathy is not possible, because one or both parties do not cooperate in this, then the tacit knowledge cannot be transferred39. Finally: 3. If empathy is a successful method, then cases of unsuccessful transfer must be 'solved' by adding empathy to the same situation. And in general, it may be that only the presence or absence of empathy can make the difference between successful and unsuccessful transfer of tacit and personal knowledge.

Empathy in the practice of nanobiology

Successful transmission of personal knowledge

In the previous section, I presented some cases of personal knowledge and how they are communicated, transmitted from person to person.

In section 2: Tacit knowledge, I discussed Collins' (2010) own research, on the installation of lasers. He observed that only people who had received demonstration and guided instruction, managed to install a laser themselves. We also saw the way new people that arrive in the Bionanoscience department of the TU Delft are taught to use the microscope. They, too, are provided with a demonstration and guided instruction. I discussed some personal examples regarding the transmission of the tacit skills needed for the proper execution of an experimental protocol. In my experience, I needed to learn how to perform an experiment by seeing it a couple of times and then being supported by on-the-spot guidance. The same turned out to be true for conveying tacit skills. When I had to teach my

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37 Maybe it's the only method, maybe there are more unknown methods.

38 If empathy is the only method, then we should also see that if tacit knowledge is transferred, then there is also empathy.

39 Or the chance is smaller (because it then has to be done via another, as yet unknown way)

own protocol to other students and researchers, I found out again that demonstration and on-the-spot guidance was the only way to successfully transfer my tacit skills. Even the experienced researchers in the lab needed to at least observe me performing the experiment in person, before they could perform it themselves. Finally, these observations have been confirmed by some researchers from the Gijsje Koenderink Lab, during the interviews. These PhD students reported that they needed to "feel like the experience is with me in the room" and "feel like they had done it before". These are cases of empathy as we have defined it.

I also considered cases of successful transmission of dispositions. Scientists know that not all decisions can be based on objective knowledge and literature. They take a lot of information and instructions from other people. Trust is an important factor here. Because the scientists know that there are a lot of personal dispositions contained in the views, experiences and findings of the others scientists, they tend to be selective about whose input to trust. Trust can be facilitated by a sense of (relative) authority: status, position and success. For example, famous scientists or professors are often trusted by other scientists. If there is no difference in scientific rank, I observed that scientists usually trust a publication or report from someone that they feel has gone through the same experiences, has a similar way of working and reasoning. In the cases of both verbal and written communication, scientists want to be informed in a way that they feel like they can follow the presented reasoning and interpretation through the first person. These examples and descriptions are cases of empathy, too.

In conclusion, we see that when personal knowledge is transmitted from one scientist to another successfully, it happens via empathy. Both the transmission of tacit skills and personal dispositions are most successful when the *receiver* of the information is able to get a second-person perspective on the instructor's or narrators experience. The examples of successful transmission correspond with our working definition of empathy.

Unsuccessful transmission of personal knowledge

We considered examples of failing attempts at transferring personal knowledge, too. In chapter 2.1 Personal knowledge in philosophy of science, we discussed Collins's analysis of tacit knowledge, knowledge that cannot, or cannot easily, be explicated. Tacit knowledge requires a special transmission. According to Collins (2010), this type of knowledge cannot be transferred in a 'string'. The example of specialized mechanics showed that the tacit skills needed for installing a microscope were not successfully transmitted when communicated by words and text. We saw clearly in this example that empathy was needed, which could be attained through demonstration and guided instruction. This example from Collins's own research is informative because of it allows for comparison. In this case, I conclude that where transmission of personal knowledge, tacit skills, was failing, empathy was missing. There was another example I discussed that allows for some comparison between transmission of skills with and without empathy. When transferring the knowledge on how to perform the cDICE or eDICE protocol, I observed this: firstly, the written transmission had failed in my lab. The researchers needed years to recover the knowledge on how to perform cDICE. Furthermore, I tried to convey my knowledge on how to perform the eDICE experiment by text and images, but failed. When I changed my method into allowing others to experience the experiment from a second-person perspective, the transmission of this knowledge succeeded. In these two cases, empathy made the difference between success and failure of personal knowledge.

Regarding transmission of dispositions, we did not have as good comparison material to consider communication of the same information, with and without empathy. An additional problem that arises with dispositions is that they are often hidden[40]. However, we did see cases in which empathy was not facilitated and cases in which it was. In these examples, trust and belief or conviction depended on the ability of one scientist, to feel like they had experienced the same as the other scientist, next to receiving purely the experimental results and analysis. The narrator is required to allow for an empathic reception of their findings, before the receiver is able to trust, understand, or believe them.

When empathy is not only used in the transmission of personal knowledge, it is the missing component in the communication. The emotional or dispositional feeling of trust, which means, trust in the other's report that is not based on authority or substantial literature, depends on one's ability to experience the dispositions in the report. Before one trusts the other's reasoning, decisions and interpretation, they need to feel like they can follow it, like they can walk along the steps of this reasoning themselves.[41]

Empathy, or just demonstration and transparency?

There is one thing that I want to discuss before drawing any conclusions. Is it really empathy that we are observing in these examples, or is it merely demonstration of skills and transparency of reasons? Situations that allow for empathy usually include demonstration with regard to tasks and transparency with regard to decisions and interpretations. Could it be that the successful transmission of skills is caused by the fact that these situations simply include demonstration? Demonstration is usually a better way to explicate information that cannot easily be put into words. And could it be that in order for someone to trust the other, they need the other to simply be transparent? Usually, transparency is needed before trust can be created. Why would we think that we are seeing empathy, and not just transparency in communication (for dispositions) and complete information in the form of a demonstration (for skills). Maybe the successful transmission of personal and tacit knowledge can be explained by these concepts only. Is it possible that we do not need the concept of empathy to explain the given examples?

Empathy is an act that enables one to experience a foreign experience from a second-person perspective (Stein, 1964). As we saw, this type of empathy includes *affective matching* and *other oriented perspective taking* (whilst maintaining a self/other differentiation, this is the second-person perspective) (Coplan, 2011). It thus allows one to have an experience of a foreign experience. We could phase a second-person perspective as a first person experience of an experience that does not feel like your own. Furthermore, I argued that one needs to be addressed before they can engage in an empathic act. In the last examples, we see that the scientists explicitly mention having or aiming to have an experience like this. In the first

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[40] Dispositions are usually regarded by scientists in natural science as unscientific. (Even though they admit to use emotion and intuition themselves.) To this problem, I formulated a solution in chapter 3. Feminist philosophy of science has convinced me that personal knowledge can be seen as scientific knowledge. Furthermore, dispositions/subjective aspects of knowledge should be made clear and explicit, in order to facilitate the creation of objective knowledge.

[41] This is still a second-person perspective. They want to follow the others' reasoning *as* themselves. So they do not want to become identical with the other. When walking along the others' lime of thought, one does get a sense of their dispositions, be it only implicitly.

example, the scientist seek to share experiences with the other. Because they cannot be present at the other's work, they look for some indirect empathy, empathy through imagination, which is possible by knowing both the person, their way of working, and the activities, their experimental methods. This allows the researcher to feel like they have had a second-person perspective on the other's experience. If they would not need to feel empathy, it would be enough for them to know all the details of their work, they would not need to be similar to the other. In the second example, the scientist said explicitly that she wanted to follow their reasoning from the first person. This seems to require more than merely transparency about facts and reasoning. She explicitly says it that she wants to have *the experience* of doing that reasoning too. Also, a scientist that function as the teacher of a tacit skill, reports that she aims to produce such a text that it made the student feel like she was there in the room with them, and she could share her experience with the student. To accomplish that, she writes the instructions to be as complete as possible about *everything* she does when handling the microscope as possible. To me, it sounds like she is aiming to come as close as possible to providing the student in acting empathically towards the text that she has written. Because, in addition to writing down the entire demonstration, she also wanted the student to have that second-person perspective experience, "like she was in the room with her". Finally, the description of the researcher's own demands on how to learn a protocol differs from merely a demonstration, because he wishes to "have the feeling that he has done it before", which corresponds to having a second-person perspective experience, in addition to a demonstration.

We thus conclude that there is good reason to believe that scientists do act empathically whilst receiving scientific reports, of any kind (instructions, demonstrations, stories, papers). They seem to require more than just transparency and demonstration, and they seem to do so consciously. The fact that they explicitly report the desire to have a second-person perspective experience, in which they are able to experience the physical activity or the mental reasoning of the other, is a reason for me to believe that empathy is the method that they are using. Furthermore, the examples show that empathy can make the difference for a scientist between successful and unsuccessful transmission of personal and tacit knowledge[42]. It seems that besides transparency and demonstration, scientists need empathy for successful transmission of personal and tacit knowledge.

4.3 Empathy as a method for transferring personal knowledge, and a value in science

To transfer knowledge that is personal, knowledge from a source that is accessible only to the individual holding it, one needs to transfer more than knowledge of explicit facts. Before this personal knowledge can be accessible to another, the other needs to share in a way the same experience. Sharing the experience allows the other to access personal knowledge from a second-person perspective. With regard to dispositions, even though one might not feel the emotions or intuitions as one's own, one is able to access them as a derivative of the others' experience. One does not necessarily agree with the decisions of the other, but one understands and trusts the presented reporting as a result. Other personalized knowledge,

[42] The examples are not a proof of my claim, but they are my reason for believing what I suggest here.

like tacit skills, can be transferred too as an experience of the other's experience. This corresponds to all characteristics of an empathic act. Empathy is now already used for the transmission of personal knowledge, especially with respect to tacit skills. There are strong reasons to believe that when decisional dispositions are successfully transferred, it happens via empathy too. It seems that all personal knowledge requires an empathic act to be transferred to another person.

Reiterative empathy (Darwall, 2006) is important for trust. In order for one scientist to trust the other during communication, both need to participate or facilitate, in order for a successful empathic act. When reporting scientific findings, the narrator needs to ensure that the reporting allows for the other to emphasize with this experience. This is often not the case in communication in the field of nanobiology.

I suggest that empathy should be the method for transmitting personal knowledge in natural science. Because of its beneficial effect on the transmission of personal, scientific knowledge, empathy should be regarded as a scientific value in nanobiology.

5. Discussion

Can we call dispositions knowledge?

Throughout this thesis, I have argued that dispositions are part of what we call knowledge/should be considered sources of knowledge. Emotions, intuition, can we really call that knowledge? It is very likely that many philosophers will not count this as knowledge.

I have chosen to call dispositions (personal) knowledge. I think that both of them are 1. Scientifically relevant, and 2. Personal. They play an important role in scientific acting and decision-making, and they are accessible to their 'owner' only. In the previous chapters, I have shown why and how the combination of these characteristics cause similar problems for dispositions and skills, with regard to acceptance and transmission. Calling both of them personal knowledge had the practical advantage that it made it easier to discuss, and more apparent, how these problems are similar. Furthermore, I stand by the claim that dispositions are a part of knowledge, as I explained In chapter 3.

What happens without empathy?

That a skill requires empathy to be transferred from one person to another, does not mean that it is necessary to apply empathy before someone can learn this skill. Someone can always learn a skill by themselves. They will just have to start from scratch, using only documentation. They probably will be able to master it one day and perform the designated task. It will be like the example I discussed concerning the protocol of the cDICE experiment in chapter 4: Unsuccessful transmission of personal knowledge, which was not transferred from person to person the first time it had been developed in my lab. Successive researchers in the lab finally got this experimental protocol to work again, they were able to produce the expected results reliably. The tacit skills were not transmitted, however, they were developed once again from scratch. In the example of the cDICE protocol, it took multiple years to get it back to work. It is extremely time-wasting when pioneering nanobiologists are forced to redo years of research because of a lack of knowledge transfer. Still, it is not always a problem to let students develop a tacit skill from scratch. Even though all natural sciences might contain tacit skills that can only be transmitted using empathy, it might not always be important or even worth wile to do so. It is mainly with regard to very complicated, specialized and new, unknown tasks, that it is wise to transfer the tacit skill properly from person to person in the empathic way I propose. Otherwise, it might take a lot of effort to retrieve or redevelop these skills.

Could one empathize with a robot?

A robot could carry all the knowledge on how to pipette correctly. Could we learn this tacit skill from the robot's demonstration and guided instruction? This question aims to find how crucial empathy really is, or what the limits of empathy are.

There are many aspects of successful transmission that a robot could facilitate: both demonstration and guided instruction, at least. I think that before a robot could provide a useful demonstration and guided instruction, they would have to be very much like a human. They would have to be very much like a human physically, because their instruction would otherwise be useless to a human. An exaggerated example of a robot that is not like a human in any way will clarify this claim: imagine a sowing machine stitching two pieces of cloth together, with a complicated stitch. Watching the sowing machine closely and repeatedly is hardly going to help a human that wants to know how to perform this task manually. Furthermore, the robot must be a bit like a human in mind too. The robot should at least be aware of how a human motor system works, how performing a certain task feels for a human body, etc., in order to properly explain. The robot should thus be very much like a human. A robot like that would possibly be so human-like that one would indeed be able to engage in an empathic act towards them. Similarly, I think that it is possible to catch an instruction on video in such a way that empathic transmission is possible. Thus, I think that empathy is necessary, but human, physical presence or interaction is not, the presence might also be human-like, and the interaction might also be digital.

Does a second-person perspective experience exist?

An important question with regard to the feasibility of this thesis is whether the reader accepts the definition of empathy that is given, and whether they believe in its existence. I have discussed the feasibility of the different definitions of empathy before, in chapter 4, and I will discuss some aspects of the second-person perspective in detail here.

Firstly, I think that the degree of proficiency in empathy differs strongly per person. Empathy is a cognitive capacity, probably comparable to capacities like spatial awareness and self-reflection. There are great individual differences in how well people are accomplished in these acts. It might be the case that the reader does not recognize the description of an empathic act that Stein, Debes, Coplan, PhD students from my lab, and I have given. Presumably, this is partially a result of talent. That does not mean that a scientist is left to their empathic powers, as written in their genotype. I think that empathy is a capacity that one can, and maybe should, train, just like self-reflection, or any other cognitive capacity.

The fact that there are many people that have experienced and described such a second-person perspective, indicates that this phenomenon exists. The similarities between the analytical, philosophical accounts of empathy and the descriptions given by the interviewed scientists of their own experiences was remarkable. For me, it was striking that PhD students in nanobiology with a background in physics, chemistry or computer science used phrases that were so strongly resemblant of my definition of empathy. This supports the second-person perspective definition of empathy and indicates its descriptive power.

Only two PhD students and me are shown to experience empathy in the context of personal knowledge transmission in nanobiology by what I have written in this thesis. The empirical data that I provide in this thesis is few. This thesis is not a thesis in psychology or any other empirical science. My experiences and the experiences of the other scientists in the lab function as a support for the philosophical analysis of the concepts that are considered. I generalize these observations in the philosophical analysis of the phenomena and concepts. I do think these philosophical analyses potentially apply to all transmission of personal and tacit information. Because this thesis also aims to convince the reader that empathy is precisely that: the transmission of personal experiences.

Effect of the choices in this working definition of empathy

I have argued that the second-person perspective definition of empathy is philosophically more powerful and feasible, compared to the other definitions. What would change if we disagree on *what* empathy is? How would it affect the conclusions if I choose a first-person perspective or third-person perspective definition of empathy?

A first person definition of empathy would allow for similar conclusions. It would more straight forward to argue that emotions and other personal dispositions could be transferred by using empathy. A first person-perspective definition allows for an identical experience. We could thus be sure that empathy has the ability of transferring skills and dispositions. However, it would necessitate two people that have succeeded in empathy, to agree with each other[43]. In this thesis, empathy is regarded as a method that facilitates access to and understanding of personal dispositions. A second-person perspective definition of empathy allows for that.

A third-person perspective definition of empathy would not allow for any of the conclusions in this thesis, except for the ones concerning feminist philosophy of science. A third-person perspective definition of empathy is, as I concluded before, a philosophically very uninteresting concept.

The chosen definition of empathy thus effects the possible conclusions one can draw on the role of empathy in nanobiology. The second-person perspective definition seems to be the most feasible, accurate, and potent one.

Possible disadvantage of empathy as a norm in large scale communication

When we say empathy is the norm for transmission of personal knowledge, we might lose the possibility of large scale transmission of personal knowledge. This however is not something we once had and have now lost.

With our new knowledge on the function of empathy in transmission of personal knowledge however, we might also improve large scale transmission of personal knowledge. Tacit skill knowledge, for example the ability to perform a certain experimental protocol, has been one of the important examples in this thesis of cases portraying problematic transmission of personal knowledge. People have hoped and tried to transfer these skills by written texts, sometimes supported by pictures or images. This does not work to convey personal knowledge. Scientists have also tried to transfer the skill of executing a protocol via audiovisual material. This also fails to do the trick. Now we know that we need to be able to perform an empathic act, we might adjust our large scale communication to allow for that.

For the transmission of tacit skills, we saw that scientists need the feeling that the experience is with them in the room, or that they have the feeling that they have done the experiment before. We might start by making an audiovisual instruction of an experimental protocol without editing, filmed by another scientists that is also learning the experiment. The instructor is then able to empathize with the student, and vice versa. When watching the video, another student has the experience of this. We might even go a step further and create a virtual reality experience for students.

Concerning dispositions in decision-making, we might enable empathy in large scale communication even more easily. In a meeting, or at a conference for example, the scientists could tell about their scientific endeavours in a way that enables empathy. A way to do this would be to take the listener along in your personal experiences when relevant. One could emphasize "I felt like" "I feel that" "My intuition says that". The emphasis would at least improve the communication of subjective aspects, which is beneficial for science, as

[43] Next to assumption that two people can have identical experiences through empathy, without a self/other distinction. This is problematic in my opinion.

discussed in chapter feminist philosophy of science. In addition to that, emphasizing personal aspects of experiences and thoughts, might enable empathy in the listener. Although empathy seems like a demanding norm that does not allow for large scale application, our insights in the role of empathy might actually simplify the difficult task of large scale communication.

Necessary and sufficient requirements for transition of personal knowledge

In chapter 4 I discussed whether demonstration and transparency were sufficient conditions for successful transmission of personal knowledge, without empathy. In this paragraph, I consider whether empathy is a sufficient and/or necessary condition for successful transmission.

What I have said in chapter 4 about demonstration and transparency not being sufficient, already implies that empathy is necessary. There are two main reasons for this, a theoretical and a practical one. Firstly, because of the theoretical fact that skills and dispositions cannot be transferred via words (or other strings, see Collins (2010)), we know that something else is needed. Empathy is exactly that: the transmission of personal knowledge via a second-person perspective experience. It seems therefore that empathy is necessary for the transmission of personal knowledge. In addition, my observations and the experiences of the other researchers agreed with this. The scientists explicitly and consciously aimed for a second-person perspective experience during transmission of personal knowledge.

The next question is whether empathy alone is also sufficient. I do not know whether I can state this or the opposite. It is hard to say whether empathy is enough when two scientists are in complete disagreement. A second-person perspective experience might be very hard to attain, and it might not suffice. When one has a completely different perception, disposition, method, or approach, the other might not trust them or disagree with them still. If the empathic act was truly successful, however, it is likely that one will understand their point or even judge them to be reasonable, given their disposition.

It is not easy to arrange your lab in such a way that empathy is guaranteed. Even when a professor would agree with this thesis, they would never be able to create the infrastructure in their lab to guarantee perfect successful transmission of all personal and tacit knowledge in their lab. Instead of regarding empathy as being a necessary or sufficient requirement, I think it functions best as an awareness and an approach. For the average natural scientists, it would be beneficial to be conscious of the fact that 1. Personal knowledge is scientifically relevant, and thus its transmission is, and 2. For transmission of personal knowledge, we need to have an experience of that personal information ourselves. This is defined as empathy. What a scientist should do is try to practice this in both directions. In transferring their own findings, they should allow the receiver to have a second-person perspective of their experience. And, in receiving information that depends on personal knowledge, one should try to take this second-person perspective whilst receiving. Practising this empathy consciously is needed, and will facilitate improved transference of personal knowledge in natural science.

6. Conclusion

Recapitulation

In the previous chapters, I have introduced the problem concerning the use of personal knowledge in nanobiology. I posed three sub questions: "What is the role of personal knowledge in nanobiology?", "How can we accept the use of personal knowledge in nanobiology or any natural science?", and, if so, "How can personal knowledge be transmitted in the scientific practice?" towards answering the main research question: "What is the (possible) role of empathy in nanobiology?"

In my analysis, personal knowledge has two important functions in nanobiology. I used both extensive examples and philosophical reflection using contemporary literature to endorse this. Personal knowledge can be found in the form of skills, like pipetting, used to perform experiments. These skills are physical. They are thus inherently personal, they apply to one's own body, and how one is able to use it. These skills are usually difficult to translate into words, and can therefore also be called tacit knowledge. The second role of personal knowledge is creating motivations for decisions in scientific dilemma's, of which the theory is indecisive. Many scientific dilemmas are in fact like that, and I have explained why scientists thus need personal input, like emotions, intuitions, or insights, to make decisions in these situations. I called these personal input dispositions, and refrained from making any distinction between them or saying anything about their origin. I did endorse that dispositions are also hard to put into words. As we know from our own experiences of trying to formulate our emotions properly. I have argued that the problem with regard to tacit, personal knowledge in the practice of nanobiology is twofold: Firstly, it is not accepted because of its subjectivity, whilst nanobiology is a natural science, concerned with objective facts. Secondly, even if personal knowledge is accepted as scientific knowledge, mainstream scientific communication methods do not allow for the transmission of information that can not be put into words.

To the first problem, I formulated a solution from feminist philosophy of science. I argued that personal knowledge should not be regarded as unfit to play a role in natural science. First, scientists need some personal input, because it is not possible to use only theoretical and objective input when one is discovering the unknown. Therefore, creating objective knowledge does not entail the exclusion of personal knowledge from the practice, it means that we regard our – necessary! - personal knowledge critically. Every empirical observation is (at least partially) personal, every scientific interpretation that goes beyond the facts is (partially) personal. We should not try to hide this, that will only sit in the way of transparency and getting rid of the subjective aspects of our general knowledge.

The second problem then remains, or even arises. If personal knowledge is scientific knowledge, or scientifically relevant, it needs to be transmitted. I suggested that empathy is a method that theoretically provides transmission of tacit knowledge. This is supported by the examples where empathy was observed to make the difference between successful and unsuccessful transmission of skills and dispositions, and by the fact that nanobiology PhD students who have never studied philosophy reported experiences so similar to our description of empathy. If this is the case, empathy could possibly have a greater role than it currently has in nanobiology. All cases and contexts where transmission of personal and tacit knowledge fails might be solved by the application of empathy. Where transmission of skills is attempted through a method that does not allow for empathy, scientists might improve this transmission by allowing for empathy and acting empathically. Especially with respect to the transmission of dispositions, empathy could be used as a means to clarify one's position and scientific propositions, and to persuade the listener to adopt a certain disposition. The full potential of empathy is possibly the transmission of all personal and tacit knowledge. I argue that if this is the case, empathy could be seen as a value in nanobiology.

I have explained why I think that empathy does exist. This belief is strengthened foremost by my own experiences, secondly by the reporting of my fellow scientists, and lastly by the fact that many great philosophers have endorsed it. I proposed that empathy is a necessary condition for belief or conviction of dispositional reasoning. (Unless there is coincidentally sympathy. But before sympathy can truly arise, one must be in position to know the other's experience, too.)

Relevance

All experimental research contains experimental protocols and their respective required tacit skills. The conclusions I have drawn in this thesis apply to the transmission of all tacit skills. In nanobiology, the transmission might be especially critical, because the experimental circumstances and practical tasks are relatively difficult[44]. However, practical challenges are a part of any experimental science. One of the prominent examples that I discussed in the previous chapters was the use of a microscope. Using a microscope is part of many fields of natural science. I have only drawn examples from scientific fields closets to my own experiences in physics, nanobiology and philosophy of science. However, I am sure that there are many examples like that from other experimental contexts. It is likely that all natural sciences contain tacit skills that require empathy to be transferred from person to person. Furthermore, dispositions are needed in all fields of science. Personal input is required, in every context where theory is indecisive. This means that every scientific practice need personal dispositions of the scientists to develop.

Empathy might be a general method for transferring personal and tacit knowledge. If this is the case, my conclusions on the role of empathy apply to all fields of natural science, and maybe even more branches of science. If this theory is widely accepted, scientists would be able to apply this knowledge in their daily scientific practice. For every transmission of tacit or personal knowledge, they could provide and engage in empathy. This realization could possibly change the way scientists communicate, and cause the creation of new standardized methods in natural science: macro scaled empathy.

Reflections

In my answer to my main research question, there is a tension between analytical philosophy and empirical evidence. I use both types of reasoning to support my claim: empathy is a method for transferring personal and tacit knowledge. My theoretical analysis of empathy shows that empathy could be a good method for passing on tacit knowledge. It is interesting to test this in reality. My examples have given an indication. They do not contradict the

[44] As I have explained before, the scientific field is relatively new and quickly developing. Therefore, many experimental protocols are new, not fully refined, and require home-made equipment. Furthermore, the samples are very sensitive.

theory, and in some cases seem to confirm the theory. This is not yet sufficient empirical evidence for my suggestion. Providing empirical evidence for my thesis is also outside the scope of this philosophy thesis. To test this philosophical theory, it would be valuable to do additional empirical research. First, it would be interesting to conduct similar interviews with many more nanobiologists and also scientists from other natural sciences. Furthermore, it would be interesting to also do research that tries to test the effect of empathy directly. It would be possible to instruct scientists to communicate in different ways and see what the effect of that is. It would also be possible and interesting to look for the limits of this: if we film the demonstration of an experiment in a way that is better allowed for empathy, is the knowledge transfer of this tacit skill also (more) successful? Empirical research can give us more insight into this philosophical theory.

Recommendations

Additional philosophical research could also contribute to this thesis. More philosophical research could be done on empathy in the context of natural science. Could the possibility of a first-person empathic experience be much more useful for passing on personal knowledge? Would it perhaps be possible to interpret the experiences of the scientists as a first person empathic experience? Is it feasible to defend a first person definition of empathy?

Philosophical research is needed to contemplate possible ways to transfer tacit and personal knowledge. Philosophers of science could for example analyse the requirements for empathy. How can one share their experience in such a way that it facilitates empathy? How does one engage in an empathic act themselves? Philosophy of science should be less concerned with the fact that emotions, intuitions and other types of subjective knowledge are used in natural science. There is no clear distinction between where subjective stops and where objective begins. However, people, and especially scientists, have a good feeling for when something is proven, and what the dependencies of their knowledge are. The fact that they are supposed to act like there are no dependencies is a bigger problem than the dependencies themselves. Thus, philosophy of science should start worrying how scientists can communicate personal and tacit aspects of science, not how to (pretend!) to get rid of them.

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