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OPAQUE AND TRANSLUCENT EPISTEMIC DEPENDENCE IN COLLABORATIVE SCIENTIFIC PRACTICE

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ABSTRACT

This paper offers an analytic perspective on epistemic dependence that is grounded in theoretical discussion and field observation at the same time. When in the course of knowledge creation epistemic labor is divided, collaborating scientists come to depend upon one another epistemically. Since instances of epistemic dependence are multifarious in scientific practice, I propose to distinguish between two different forms of epistemic dependence, opaque and translucent epistemic dependence. A scientist is opaquely dependent upon a colleague if she does not possess the expertise necessary to independently carry out, and to profoundly assess, the piece of scientific labor which her colleague is contributing. If the scientist does possess the necessary expertise, I argue, her dependence is translucent. However, the distinction between opaque and translucent epistemic dependence does not exhaust dependence relations in scientific practice, because many dependence relations are neither entirely opaque nor translucent. I will discuss why this is the case, and show how we can make sense of the gray zone between opaque and translucent epistemic dependence.

Epistemic dependence is ubiquitous in collaborative research practice, and this paper seeks to add to a philosophical understanding of dependence in scientific knowledge creation. If we seek to formulate a social epistemology of scientific practice, however, we need to refine the vocabulary that we have. Philosophy's conceptual tools have to take into account that the relations of epistemic dependence between practicing scientists vary. No one size fits all. In order to get a grip on epistemic dependence as experienced from the perspective of scientists, a subtle and practice-minded terminology is needed. Paul Thagard has suggested a distinction could be made between four different collaborative relationships: employer/employee, teacher/apprentice, peer-similar and peer-different (Thagard, 1997). This is a starting point, but an understanding of epistemic dependence in collaborative practice requires a distinction that cuts deeper and addresses underlying issues of expertise. As I will argue, crucial to configurations of epistemic dependence is whether, to what extent and in which way the dependent person has the possibility to make use of expertise. Based on an empirical case study, I propose to distinguish between translucent dependence (which is cushioned by the dependent person's expertise) and opaque dependence (which is not). As I will point out, this distinction does not exhaust the phenomenon of epistemic dependence. Nevertheless, it provides two cornerstones in relation to which a variety of instances of epistemic dependence can be understood.

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To unfold this distinction, the paper proceeds as follows: Section 1 explains how epistemic dependence arises from asymmetries in epistemically relevant resources. Section 2, then, reviews some of the work on epistemic dependence that has been undertaken by epistemologists so far. Thereafter, section 3 introduces the reader to the comparative case study which underpins my reflections. Finally, in section 4 I elaborate on my distinction between opaque and translucent epistemic dependence. Section 5 concludes the paper.

1. STARTING POINT: RESOURCE ASYMMETRIES

When scientific labor is divided among the members of a research group, group members come to depend upon one another.[1] The creation of scientific knowledge requires epistemic labor. Evidence has to be gathered, arguments have to be set up. They rely upon one another for the evidential and argumentative bits and pieces that are eventually to be integrated into a well-corroborated, publishable scientific knowledge claim.[2] Therein, scientists come to depend upon one another *epistemically*: In their judgment of scientific quality, single scientists will come to depend crucially on the judgment of their collaborators. That is, they will come to rely upon others for their personal, doxastic attitudes and the justification of those.

Epistemic dependence in research groups arises from asymmetries in the resources that team members can bring to the group and from the way, taking into account those asymmetries, work is organized within the team. These resources comprise expertise, but also particular experimental devices, time, 'sheer' labor, social capital, etc. By expertise I refer to manual and cognitive resources, both declarable and tacit, such as experience and technical skills that are acquired through a process of professional maturation (cf. Collins and Evans 2007; Collins 2013). Expertise typically is, as most resources, limited and unevenly distributed among team members. I will elaborate on different forms of expertise at the end of section 4.

Yet, the division of epistemic labor in groups does not only take into account existing differences in epistemically relevant resources – it also creates new epistemic asymmetries. As epistemic labor is distributed among team members, so are the immediate fruits of these efforts. This is most palpable in the case of laboratory work. Depending on the distribution of laboratory tasks, some team members will have the possibility to eyewitness experiments and take measurements, while others will not. While some team members will have the possibility to familiarize themselves intimately with a dataset and draw inferences from it which are required to make an interpretation of the data, others will not. In lieu of

1 I am convinced that epistemic dependence is a form of dependence that is of utmost importance in scientific practice, and is the form of dependence one needs to focus on if one seeks to shed light on the collaborative creation of *knowledge*. Still, I am aware that scientists do not only depend upon each other for epistemic purposes. For a broader, social-scientific account of dependence in science see Whitley (1984: 87ff.).

2 When I use the terms 'to know' or 'knowledge' I refer to an understanding of knowledge as justified (true) belief. This is not to say that there is no tacit knowing or that such knowing would be peripheral in scientific practice (cf. Polanyi 1958). Tacit knowledge is an important component of scientific expertise. Yet, when I speak of epistemic dependence in this paper I confine myself to the inter-personal transfer of explicable pieces of information that collaborating scientists assemble in their effort to formulate and corroborate a publishable scientific knowledge claim.

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their 'own' perceptual experience and/or inference, the latter will have to rely upon the measurements taken and the interpretations made by their colleagues. It is convenient to use 'first-hand' and 'second-hand' knowing to describe constellations such as these (Fricker 2006). To speak of first-hand knowing in the case of scientific practice, however, should not mislead to think that scientific knowledge can be had by any individual in completely self-reliant ways. Even knowledge which is related seemingly immediately to observation is likely to be mediated by theory and theory-based instrumentation. It would be wrong, however, to infer from this that there are no epistemically significant differences between a scientist observing an experiment and a fellow colleague relying upon her observation.

It is obvious that some epistemic asymmetries are more fundamental than others. Differences in expertise that have been accumulated throughout a scientific career can hardly be cleared out. Some epistemic asymmetries, however, can be mitigated. Data measurements that were taken in the absence of a collaborator can be repeated in her presence. If there is time for it, the interpretation of the results from an experiment already concluded can be discussed again with the help of a team member who has been bound up in other duties before. But time is precious, materials expensive and sometimes attempts to cross-check each others' work within the team can be perceived as inappropriate skepticism.

2. THEORETICAL GROUNDWORK: EPISTEMIC DEPENDENCE RELATIONS

In this section, I lay the conceptual groundwork for the distinction between different forms of epistemic dependence that I introduce in section 4. I will do so by revisiting accounts of epistemic dependence that Robert Audi and John Hardwig have formulated.

According to Robert Audi, epistemic dependence is '(roughly) the sort of relation that holds between one belief and another (or between a belief and something else) when the former depends on the latter either for its status of knowledge or for whatever justification it has' (Audi 1983: 119). Audi thus conceives of epistemic dependence as a belief–belief relation that concerns the epistemic justification of one belief in relation to another. Put differently, Audi's notion of epistemic dependence does not concern the transmission of ideas, thoughts or reflections, but their epistemic status as justified beliefs that qualify to be called 'knowledge.' What underlies Audi's account of epistemic dependence – and, as we will see, Hardwig's account as well – are scenarios of testimonial knowledge transfer.[3]

What Audi offers is an abstract, static view on the architecture of beliefs and their epistemic justification. Whether or not these beliefs are held by individuals, and how these individuals interact is of little concern to Audi. In contrast to Audi, I am not interested in static belief–belief relations. Rather, I am interested in the dynamic relations between one scientist's knowing on the one hand and another scientist's expertise, as manifest in his knowing *and his epistemic labor* on the other hand.[4] When a scientist's knowing,

3 A thorough discussion of testimony lies outside the scope of my work. See Coady (1992) for a definition of testimony as an epistemological term and a discussion of testimony as source of knowing.

4 Goldberg (2011) shows that epistemic dependence extends beyond two-person-relationships. In fact, he argues, in the formulation of well-founded beliefs a person depends not only on eyewitnesses and

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i.e., her believing-that and/or the reason for her believing to be justified, crucially involves what her colleagues know or the epistemic efforts that they have undertaken, then we have a case of epistemic dependence. To take into account not only beliefs and their epistemic relations, but epistemic labor as well means to involve the material dimension of scientific practice in epistemological reasoning. It means to go beyond an exclusively cognitive, internalist notion of epistemic dependence like the one proposed by Audi. This aids an understanding of collaborative scientific practice as cognitive *and* material practice that makes constant use of physical devices such as samples and tools. In fact, experimental evidence is mostly conveyed in a material form, i.e., as a photograph, a copy of the laboratory notebook, a print, a frozen sample, a concrete model, a diagram, or a file.[5]

In experimental practice, it is quite common for scientists to rely on experimental work produced by their colleagues. This reliance upon 'foreign' labor, e.g., upon a particular dataset, is an instance of epistemic dependence, albeit not one that is appropriately characterized as belief–belief relation alone. Let me explain why with the help of an abstract example. An experimental scientist *B* depends on her colleague *A* for a couple of measurements. *A* may hand *B* a file with all measurements made and *B* may access the data in the absence of *A*. If these measurements show that *p*, then *B* can form the belief that *p* when she sees those measurements or is told about them and she can justify her believing that *p* by reference to those measurements. As these measurements possess a material quality that make them physically accessible, i.e., accessible not only through the measuring scientist *A*'s mind and his believing, the dependent scientist *B* may justify her believing in ways other than by reference to *A*'s believing that *p*. Of course, these measurements are permeated by beliefs that the measuring colleague *A* has. It has to be assumed that *A* believes these measurements to be good. Also, making scientific measurements is a task that requires reflection and would not be possible without the agency of a belief-forming individual. Nevertheless, it would be short-sighted to characterize this instance of epistemic dependence as a simple belief–belief relation. Note that the measuring colleague *A* may take the measurements as showing that *not-p*. It is, after all, possible to imagine that *A* is good at handling a measuring device but bad at interpreting his measurement. But under the condition that *B*, who has not performed the measurements herself, possesses the required expertise to interpret them, *B* can take them to indicate, and be justified in doing so, as showing that *p*. Still, I argue, this is a case of epistemic dependence between two collaborating scientists. Scientist *B* relies on her colleague *A* to have made the measurements accurately and to have reported them adequately.

But why does it matter to emphasize the material dimension of scientific practice for an account of epistemic dependence? When *B* relies upon the results of her colleague's labor, she need – even in cases of epistemic dependence – not necessarily rely on his believing that *p*. She is in a position where she can make her own judgment as to whether *A*'s epistemic

experts from whom he might adopt knowledge, but he also depends on his larger epistemic community. This aspect is important, but for the purpose of investigating collaboration in scientific groups, I limit my analysis to immediate person-to-person relationships.

5 Latour's observation that scientific practice involves sequences of material 'inscriptions' comes to mind (Latour 1999). The material dimension of science has been explored paradigmatically by Rheinberger (1997), and philosophers have developed an increasing interest in the concrete artifacts of scientific practice as well (Knuuttila 2011; Bechtel and Abrahamsen 2012; Carusi 2012). For the cognitive value of concrete artifacts more generally see the literature on distributed cognition (Hutchins 1995, 2001).

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labor is evidence of *p* or not. In making this judgment, *B* has the possibility to make use of her own expertise. Given that *B* has the necessary expertise on the issue in question, she is able to assess the evidential significance of *A*'s labor with some degree of intellectual autonomy. This may help to contain *B*'s dependence upon *A*. In section 4, I will characterize instances of dependence such as this as translucent epistemic dependence.

2.1 *First- and second-order reasons*

Next, let us see how such a practice-minded understanding of epistemic dependence plays together with Hardwig's account of dependence relations in the creation of scientific knowledge (Hardwig 1985, 1988, 1991). The question of how individuals can acquire 'rational,' well-founded beliefs is the question that can guide us through Hardwig's reflections. Hardwig's point of departure is to argue that a person can rationally acquire a belief by appealing to the intellectual authority of a second person. To have a well-founded belief means to have good reasons for holding this belief. A good reason for holding the belief that *p* is to have sufficient evidence for the truth of *p*. What, however, if an individual for whom it would be important to know whether or not *p* is the case cannot have sufficient evidence neither for believing that *p* nor for believing that *not-p*? Does that mean that this individual has no possibility whatsoever of acquiring a well-founded belief as to *p*? No, Hardwig argues, and he introduces what I call *second-order reasons* for having the belief that *p*.

In my wording, *first-order reasons* for *p* are reasons that spring from having sufficient evidence for *p*. If first-order reasons cannot be had, then it is rational for an individual *B* to rely on another individual *A* telling that *p* is true if *B* has good reasons to believe that *A* has sufficient evidence for *p* (Hardwig 1985: 336). *B*'s good reasons to believe *A* in telling that *p* are second-order reasons. They do not constitute immediate evidence as to *p*, but they can, Hardwig argues, justify *B* in adopting the belief that *p*.[6] But what, then, are these good second-order reasons on which *B* can, according to Hardwig, rest his believing that *p*? *B* trusts *A* to be an honest, skillful eyewitness and/or a person with superior expertise (Hardwig 1985: 337, 339). Put differently, second-order reasons relate to the trustworthiness of *A*. In the scenario of epistemic dependence that Hardwig presents us, then, the primary question for *B* to answer is not whether *p* is right or wrong. Rather, the crucial question for *B* is: How can she rely on *A*? Is it warranted to assume the trustworthiness of *A*? More precisely put, how can *B* be sure that *A* is a 'truthful' and 'competent' expert (Hardwig 1991: 700)? If *B* possesses no expertise as to *p*, *B* will have to establish *A*'s reliability as to the belief that *p* on grounds other than the expertise at stake. In this case, *B*'s judgment to adopt or reject *p* is not based on expertise as to *p* and the expert evidence for *p*, which at least *A* is supposed to have, remains opaque to *B* (Hardwig 1985: 341ff.).

6 Contrary to Hardwig, Almassi argues that 'layperson B's good reason to believe that expert A has good reason to believe proposition *p* constitutes evidence for B for *p*' (Almassi 2007: 58). In this sense, *B* possesses evidence for the claim that *p*. Note, however, that *B*'s evidence is not the kind of evidence which meets scientific standards and will not form part of an argument supporting *p* as formulated in a scientific publication. In other words, Almassi is invoking a kind of 'second-order evidence' that may justify individual believing.

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Generally speaking, Hardwig characterizes instances of epistemic dependence as situations in which a dependent collaborator *B* in her believing that *p* resorts to second-order reasons relating to the trustworthiness of *A* (who, in turn, possesses immediate evidence for *p*). My intention is to add more nuance to this picture: If the dependent scientist *B* has some expertise on the issue in question, she may be in a position to acquire some first-order reasons, too – only that these first-order reasons do not suffice to fully justify *B* in believing that *p* in accordance with scientific standards. Therefore, *B*'s first-order reasons would need to be supplemented with second-order reasons as to the trustworthiness of her collaborator *A*. In a scenario where *B*, albeit ultimately dependent on *A*, is able to make use of her own expertise, the character of epistemic dependence is different from situations in which *B* fully relies on *A*. In order to account for this difference, I suggest distinguishing two forms of epistemic dependence in section 4. Empirical insights guided me in drawing this distinction and I will make use of them to demonstrate my suggestion to the reader. Therefore, I briefly introduce my empirical case study in the next section.

3. CASE STUDY: RESEARCH GROUP COLLABORATION

To study scientific collaboration within research groups, I have conducted a comparative case study. With a qualitative approach to empirical fieldwork, I have observed the group's weekly meetings, 'shadowed' individual group members and conducted semi-structured interviews with 10 researchers from both groups. Through interviews I have sought to establish the cognitive strategies, accumulated experience and culturally passed-down ethos by which scientists as reflective practitioners manage collaborative scientific practice. To analyze field notes and interview transcripts, I have employed descriptive and theory-inspired coding (cf. Strauss 1987; Strauss and Corbin 1990; Alexa and Zuell 2000). My analysis is necessarily confined in scope. However, I make use of my empirical insights to formulate a distinction of two configurations of epistemic dependence which I hope will prove fruitful in reflections which go beyond the case I have studied (cf. Burian 2001; Chang 2011; Schickore 2011).[7]

I call the two academic research groups that I have each studied over the course of more than a year the 'planetary science group' (group 1) and 'the molecular biology laboratory' (group 2), respectively. Both groups are situated at Danish universities.[8] The planetary science group is an interdisciplinary research team. The researchers in this group have been working together for about 10 years and they unanimously perceive this period as successful. Over this period, there have been but few changes in 'core personnel.' At the moment, the group consists of five senior scientists. Usually, there are about two junior scientists involved in the group's activities. Of the five senior scientists two are physicists. The three other core group members come from microbiology, chemistry and geology, respectively. All of them are hired on tenure by their respective disciplinary department and have

7 For other qualitative case studies in philosophy of science, see Nersessian *et al.* (2003), Nersessian (2006), Leonelli (2007, 2010a), and Riesch (2010).

8 My fieldwork took place, with interruptions, in 2010–2013. To guard group members' anonymity, I will refrain from describing their research in detail. In addition, interview passages will be, where necessary, altered and all persons quoted will be given pseudonyms. To reflect the rather informal work culture in Danish research, pseudonyms are given names.

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their own laboratory. They try and meet in person once a week – urgent personal obligations permitting. The group describes itself as having a decentralized structure and functions in a way which does not require a group leader. There is neither a discernible hierarchy nor scientific competition among the senior core members of the group, as each of them has his own specific field of expertise.

The molecular biology laboratory, in contrast, is a mono-disciplinary research team of about 35 people. Since research in molecular biology is extremely expensive, the group would not exist without the research funds that the group leader continuously applies for with great success. The group is organized hierarchically, and its hierarchy mirrors the levels of professional seniority that are present within the laboratory. Holding a full professorship, the group leader presides over the lab. Tenured or non-tenured senior researchers and six to nine post-doctoral fellows constitute a medium level of hierarchy. The laboratory comprises about 20 graduate students and undergraduate students and three technicians. The fact that I describe the molecular biology laboratory as a mono-disciplinary team, however, should not veil the diversity of academic biographies. Some PhD students have a background in programs other than molecular biology, such as medicinal chemistry or even theoretical chemistry, and some of them have chosen to take courses in neighboring fields such as bioinformatics. The variation in expertise continues at higher levels of seniority, although differences in individual specialization typically tend to be more subtle there.

3.1 Different patterns in expertise

Both the planetary science group and the molecular biology laboratory show an uneven distribution in expertise, but they do so in utterly different ways. In the molecular biology laboratory, roughly speaking, all laboratory members have, or intend to acquire the same kind of expertise. In this group and particularly within its subgroups, a gradient in expertise is palpable. Senior group members possess more expertise than junior group members. From the perspective of individual young researchers, this gradient in expertise is temporary and as they continue in the field, they will close the 'gap' that separates them from the level of expertise that senior group members possess. To become a fully-fledged scientist is to pass through all career stages, from PhD student to post-doctoral fellow to assistant professor to lab leader. As Knorr-Cetina has observed: "Owning one's own lab' [i.e., becoming a laboratory leader] is what most researchers who wish to remain in academic settings desire. Only the laboratory, it seems, completes the scientific person' (Knorr-Cetina 1999: 221). Generally speaking, PhD students are supposed to be more experienced and knowledgeable than Bachelor students, advanced PhD students are supposed to be more skilled than PhD students who have just been hired and post-doctoral fellows are supposed to outclass PhD students. This, of course, is no more than a schematic picture, but it captures the rationale which underlies the hierarchical set-up of the group. An exception to this rationale is, paradoxically, the lab leader. Since he has not been working physically in the lab a lot for the past few years, he is not expected to manually master recently developed experimental routines. The molecular biology laboratory is not unique in this gradient of expertise, which is a generally observable trend in the life sciences. Grit Laudel (2001) has described this trend as 'vertical specialization.' This form of within-group specialization 'involves the differentiation of theoretical activities on the one hand, and experimental activities on the other' (Laudel 2001: 764).

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The planetary science group is different. Vertical specialization is absent here. Also, it would be wrong to describe the differences in expertise between its group members as a 'gap' that is to be closed, i.e., a gradient from more professional capacity to less professional capacity which needs to be mitigated through learning. In the planetary science group, group members generally do not aspire to acquire the expertise which their colleagues possess. Forming an interdisciplinary group, the scientists in the planetary science group cover different fields of expertise. One possesses a kind of expertise that a second one does not possess. The second one, in turn, possesses a kind of expertise that the first one does not possess. They are both lay and expert at the same time. Each member – senior members in particular, but advanced junior researchers as well – seeks to carve out a niche within the group, often in cooperation with other team members. In addition, as I will elaborate further below, they develop the 'interactional expertise' necessary for collaboration across disciplinary boundaries (Collins and Evans 2007; cf. Gorman 2002). The planetary science group could, to borrow Laudel's terminology again, be described as exemplifying the kind of 'horizontal specialization' that is characteristic of the disciplinary and sub-disciplinary differentiation of natural science in general (Laudel 2001).

3.2 Different patterns in division of labor

The observable differences in patterns of expertise in the planetary science group and the molecular biology laboratory are reflected in the different patterns of division of labor that the two groups adopt. The division of labor in the planetary science group is best understood as cooperation inter pares in the joint pursuit of a differentially shared research object. The planetary science group distinguishes itself by a flat and soft hierarchy and a very egalitarian work culture. Although senior scientists naturally function as supervisors to students and doctoral students, the latter, if they work within the interdisciplinary realm of planetary science, usually cooperate with different senior scientists simultaneously and thus increasingly develop a rather independent way of working.

In contrast to the planetary science group, the molecular biology laboratory features a palpable hierarchy, the virtue of which is the possibility for the delegation of work 'downwards.' Instances of downward delegation are an integral element of the division of labor among laboratory members and it occurs on two levels. The lab leader delegates tasks such as the close supervision of students to post-doctoral fellows. Post-doctoral fellows distribute laboratory work among the students they supervise in informal sub-groups. Nevertheless, one should note that the kind of downward delegation in the molecular biology laboratory is a soft one which is embedded in a liberal work environment and a culture of solidarity, help, and group deliberation. It is accompanied by ideals of intellectual autonomy and individual responsibility. Roughly, the formal hierarchy in the molecular biology laboratory mirrors the gradient in expertise. Furthermore, given the gradient in expertise, 'upward delegation' is another integral element of the division of labor in the molecular biology laboratory. For relatively difficult tasks, junior group members confer with senior group members. Senior members offer generous advice, and would often perform experimental steps together with junior scientists. Group members are supposed to engage in constant learning and they help each other to learn. All group members profit from the collective effort to learn immediately, because experimental practice in molecular biology is, as pointed out, necessarily collaborative. It is better to rely on skilled

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collaborators, and it is easy to trust a colleague's skills if one has witnessed how these skills have been acquired.

Moreover, the molecular biology laboratory features many other instances of division of labor which neither involve a gradient in expertise nor formal hierarchy. These instances can be described as benevolent tit for tat. Group members help each other. When one person finds the time to monitor another person's experiments over the weekend, the latter may be able to perform a measurement for the first person at some other time. This form of mutual solidarity is vital for the functioning of the molecular biology laboratory, because experimental procedures are complex, time consuming and often take place overnight or at weekends. It is not unusual for one researcher to be occupied with several different experimental steps in different laboratory facilities at the same time and therefore they have to rely upon colleagues to inform them about potential problems before these endanger on-going experiments.

Since expertise and other epistemically relevant resources are distributed differently, and since epistemic labor is divided differently in the two groups, it stands to reason that different dependence relations predominate in the two groups. In the remainder of the paper I investigate variations of epistemic dependence relations observable in scientific practice.

4. MAKING A DISTINCTION: OPAQUE AND TRANSLUCENT DEPENDENCE

To refine the vocabulary available for analyzing collaborative knowledge creation from the point of social epistemology, I suggest making a distinction between *opaque* and *translucent epistemic dependence*.[9] A scientist is opaquely dependent upon a colleague's labor, if she does not possess the expertise necessary to independently carry out, and to profoundly assess, the piece of scientific labor her colleague is contributing. I suggest, however, that if the scientist does possess the necessary expertise, then her dependence would not be opaque, but translucent.[10] As we will see, the distinction between opaque and translucent epistemic dependence does not exhaust dependence relations in scientific practice. A range of dependence relations are neither entirely opaque, nor translucent. I will discuss why this is the case, and show how we can make sense of them within my distinction of opaque and translucent epistemic dependence nevertheless.

4.1 Opaque dependence

What I designate as 'opaque' epistemic dependence is the kind of dependence that epistemologists usually talk about. It is the extreme case of an epistemic dependence relation

9 The expression 'epistemic opacity' has been used by philosophers of science in different contexts before. Soler (2011) uses the expression to highlight the fact that tacit components of scientific practice cannot be explicated and thus remain 'opaque.' Lenhard (2006), in turn, uses 'opacity' as a synonym for the limited comprehensibility of mathematically complex simulation models, and incomprehensibility is also what I denote with the expression.

10 My distinction can be regarded as an explication of the distinction between 'cognitively necessary' and 'practically necessary' epistemic dependence that de Ridder mentions in his account of irreducibly collective knowledge (de Ridder 2014: 46). From my point of view, however, de Ridder brushes over the subtleties of what I call translucent epistemic dependence.

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which Hardwig describes and which can be formulated as a testimonial exchange: Speaker *A* tells listener *B* that *p*, and *B* has no means to establish the truth that *p* other than assuming that *A* is a competent and truthful testifier. *B* has no way whatsoever to justify her believing that *p* without recourse to *A*, because *B* lacks the expertise to acquire the justified belief that *p* by means other than reliance upon *A*'s testimony. In other words, *B* lacks the expertise necessary to establish that *p* through observation and/or some kind of inference. She does not possess first-order reasons for her belief that *p*. Nevertheless, she can try to establish the reliability of *A*, and succeed in doing so to varying degrees. The more *B* knows about *A*, his moral and professional qualities, the better she can judge his qualities as a testifier that *p* without possessing expertise pertaining to *p* herself. Thus, the dependent person in opaque dependency relations should not be described as completely naive, ignorant, or undiscerning. She can have, as Hardwig pointed out, very good second-order reasons to enter an opaque dependency relation.[11]

A lack of expertise cannot easily be mitigated. Expertise cannot be simply learnt off the book. The acquisition of scientific expertise is a complex learning process that typically stretches over years of exercise. Therefore, exemplary cases of opaque dependence can be found in both groups studied. In the planetary science group, instances of opaque epistemic dependence are particularly apparent because the group has an interdisciplinary profile. In the planetary science group, scientists with different disciplinary backgrounds collaborate in an intricately interwoven manner. Every one of them contributes to their collaboration with the particular combination of epistemically relevant resources he possesses. The use of the planetary science group's simulation facility by group members without physical expertise is a good illustration of opaque epistemic dependence. When the biologist runs an experiment in the group's simulation facility, he relies entirely upon Adam, the physicist who is responsible for this facility. The biologist is not able to operate the simulation facility. He delivers a bacterial sample to the physicist who then places this sample in the simulation facility, runs the experiment, and returns the sample afterward to the biologist for further laboratory analysis. The physicist will also report on the measurement of all experimental parameters, such as wind speed etc. Another example of opaque dependence in the planetary science group would be the reliance upon Mössbauer spectroscopy to determine the iron components in geological samples. This is an example that Laurits, the group's geologist, brings up in the interview:

> Q: Do you think that the things you have in your papers – in principle you could do them on your own? Or you could only do them with others?
>
> Laurits: If I think back I would say that in many of our publications Mössbauer spectroscopy has been used as a useful method. I started with that before Rasmus [physicist in group1] came here. With the Mössbauer laboratory in Physics. And I started to publish things with one of the persons from there, so it hasn't been necessary for me to do Moessbauer spectroscopy myself. And it's a field where you need a lot of experience to be sure of what you interpret out of the spectra you see. So, I would not be able to get the same interpretation out of that if I didn't have an expert like Rasmus. So, this wouldn't be a good way of doing publications – trying to do this as an amateur

11 Strategies for establishing second-order reasons for the reliance upon a collaborator are analyzed in Goldman (2001), Sperber *et al.* (2010), and Wagenknecht (2014).

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> yourself. So you need to collaborate with people who know more about different fields. And when it comes to sand transport, I would say that Oliver [geologist associated to group1] has spent all his life on that and he of course has a basic knowledge there that I don't have. So if we come to experience and publications in that field, I would never do it without him. [Laurits, senior geologist, group 1]

Instances of opaque dependence relations come to the fore in the molecular biology laboratory as well. There are two sources of epistemic opacity in the molecular biology laboratory. The first source is a learning lag between less experienced and more experienced group members, and the second source is specialization, both in vertical and horizontal forms. Paradigmatic for within-group relations in the molecular biology laboratory is the first source of opacity. In the laboratory, opaque epistemic dependence applies typically to junior–senior relations. For PhD students it is key to rely on the hands-on expertise of junior group leaders for the purification and crystallization of particular families of proteins. For example, Martin, a recently started PhD student, depends crucially on a post-doc's skills (Magnus) for the treatment of proteins that are known to require particularly intricate purification procedures. At the time of my interview with Martin, however, it was clear that Magnus would be leaving the laboratory soon to start his own group at a different university.

> Q: Magnus is leaving, is that a problem?
>
> Martin: I don't know. Initially I was very anxious about that, but I feel that we are getting to a point that, because we have progress, I think that within two months let's say we can do everything, because after he gave us the basic skills, then we have to just fiddle around by ourselves. Also Magnus is very accessible by emails, Skype and he clearly wants to help us and he said that of course he wants to consult with us. If we got further, then really, his experience stops being that necessary. [Martin, PhD student in molecular biology, group 2]

Here, opacity has, or is imagined to have, a transient character. Time is a crucial element in understanding these dependency relations. Because of a lack in experience, junior researchers rely on seniors – but the junior researcher expects to gain the professional capacity he is lacking at some point in the future. As the student's expertise grows, so he develops greater professional autonomy.

4.2 *Translucent dependence*

Different configurations of epistemic dependence are possible. Many instances of epistemic dependence in scientific practice are not opaque, and some of these instances are what I refer to as 'translucent.' As translucent epistemic dependence I characterize instances of epistemic dependence in which the dependent scientist does possess enough expertise to be able to work independently, yet she does not do so for pragmatic reasons.

My terminological choice may seem curious at first glance. It would be obvious to choose the attribute 'transparent' for forms of epistemic dependence that are not opaque. However, there is no such thing as 'transparent epistemic dependence.' If all epistemic issues were completely transparent to a dependent scientist, then she would not be epistemically dependent. To be more precise, let me return to Hardwig's terms. What is *not*

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transparent in cases of epistemic dependence but should be transparent in cases of epistemic *in*dependence are the sufficient first-order reasons for why the statement 'that *p*' should be regarded as reliable. Put differently, scientist *B* is not epistemically dependent when she has sufficient evidence for *p* on her own.

In the measuring example, having sufficient evidence for *p* means to fulfill two conditions: It means to possess the necessary expertise to perform and understand the measuring procedure *and* to actually perform the measurement or eyewitness it scrupulously. The first condition posits an expertise requirement, and the second condition posits an information requirement. When one or two conditions are not fulfilled, then we have a case of epistemic dependence. When *B* does not meet the expertise requirement, then we have a case of opaque dependence. While the expertise requirement may go without saying, the information requirement might seem superfluous. But as I have argued above, without having performed the measurement herself (or having overseen it closely), *B* cannot be entirely sure that the measurement has been conducted skillfully and reported truthfully by her colleague *A*. In experimental science, evidential contributions can be entirely transparent only to those who have created or eye-witnessed them.[12] When *B* does possess the necessary expertise, but has no information about how the claim that *p* has actually been created, then we have a case of translucent epistemic dependence. Translucent dependence is a form of genuine epistemic dependence because the evidence for the claim that *p*, which *B* is interested in endorsing, is not entirely transparent to *B*.

Translucent dependence is a form of epistemic dependence in which the dependent scientist *B* engages for reasons not related to her expertise in a relation of dependence with scientist *A*. Instead, *B* relies on *A* for pragmatic reasons, often related to considerations of time. But because *B* possesses expertise pertaining to the claim that *p*, *B* can at least partially assess *A*'s claiming that *p* – and, if available, *B* can assess the experimental evidence that *A* provides for this claim. Also, *B* is in a position to question *A* about the details of his claim that *p*, so that *A* is forced to argue for his claim that *p*. Moreover, *B* has more possibilities to assess *A*'s qualities as an experimenter in general. Therefore, *B*'s dependence runs not as deep as in instances of opaque dependence. Still, I want to emphasize the fact that translucent dependence is a relevant and epistemically significant form of epistemic dependence in scientific practice.

De Ridder has suggested a distinction between 'cognitively necessary epistemic dependence' and 'practically necessary' but not cognitively necessary epistemic dependence (de Ridder 2014: 46). This distinction is similar, albeit not identical with mine, and I will refrain from endorsing it for two reasons. First, laboratory skills are a fundamental component of scientific expertise so that it is fair to say that expertise clearly involves more than cognition. An opaque epistemic dependence relation that is rooted in an asymmetry in expertise, thus, is necessary for more than solely cognitive reasons only. Second, the circumstances of 'practically necessary' dependence have significant cognitive consequences: If you cannot run an experiment yourself due to a lack of time, infrastructure, or labor,

12 Often, many transforming operations are necessary to convert observations into transmissible data, and many of these operations require tacit knowledge (Leonelli 2010b; Bogen 2011). The fact that acts of observation and the transformation of observations in data are carried out by fallible agents obfuscates transparency even in cases of complete expertise.

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you cannot acquire first-hand reasons concerning the experimental evidence produced. Therefore, I believe a distinction between 'cognitively necessary' and 'practically necessary' dependence to be potentially misleading.

Moreover, I believe it inadequate to rephrase the conceptual distinction that I draw between opaque and translucent as 'insurmountable' and 'surmountable' epistemic dependence. Opaque dependence is not insurmountable. It only takes considerable time and effort to do so. In addition, to label translucent dependence as surmountable may imply that translucent epistemic dependence *should* be overcome. It is not my intention however, to make such a claim. Translucent epistemic dependence is a valuable instrument in the efficient organization of research collaboration – and as such, it is, in fact, not surmountable. It has to be acknowledged that the creation of knowledge in scientific practice is shaped, and rightly so, by the uneven distribution of various resources, not only scientific expertise. Clearly, experimental expertise is important. But the experience required to, e.g., set up and maintain an experimental infrastructure at one's disposition is important, too, and not every scientific expert does possess it.

A case in point for translucent epistemic dependence is the division of labor between subgroup leaders and PhD students. When Martin describes this relation, he tells me:

> I don't think there is a thing that Magnus would do worse than me, in the lab, nowadays. Just that he cannot do everything ... now Magnus is starting his own group and he will be moving out at the end of the year. And he probably spent half or a year getting money, writing applications, going to funding interviews. Of course, he was doing a lot of different stuff as well. But the higher you go – track record – the more it's about just getting financing. Because it's so costly. And then you have hands, you can think about this as your hands that do your experiments, in a way ... so a lot of problems that we have, and we kind of solve them by ourselves, is something [Magnus] would solve also or even quicker. It's just impossible for him to do everything. So ... there are collaborations which are because of the expertise and those are usually outside the group. But within the group ... I think it's mainly the work load. [Martin, PhD student in molecular biology, group 2]

Magnus depends on Martin and other doctoral students to establish certain intermediate experimental results, but his dependence is translucent, because he possesses the necessary expertise to fully understand all experimental steps and to, if need be, perform them himself. If he did not possess the experimental expertise, his dependence would be opaque.

4.3 The gray zone

The distinction between opaque and translucent epistemic dependence hinges upon this difference: having or not having expertise pertaining to the piece of epistemic labor at stake. It should be noted, however, that this is a gradual difference and that there is such a thing as 'partial' expertise. We hence have to speak of a large gray zone that lies between opaque and translucent epistemic dependence. In the following, I elaborate on the question what 'partial' expertise can be and how it may play out in relations of epistemic dependence.

At least two aspects, I believe, need to be added to the distinction between opaque and translucent epistemic dependence. The first aspect concerns the role of time and learning in the acquisition of expertise over time which entails that expertise may be 'partially' had (i). The second aspect concerns forms of scientific expertise which have not been discussed

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so far and which may be described as 'partially-enabling,' not fully-fledged forms of expertise (ii).

ad i. Scientists gain expertise over time. Scientific expertise is a capacity that is acquired gradually through immersion in specialist communities and the learning processes that this immersion entails. Being in the midst of this gradual learning process, students may possess 'partial' expertise. Through learning, the relationship of collaborating scientists may change over time. This is particularly obvious for student–post-doc relations in the molecular biology laboratory. The more expertise the student acquires, the less she depends upon others for their expertise. This requires us to consider the gray zone between opaque and translucent epistemic dependence in which the dependent scientist *B* possesses partial expertise relating to the piece of epistemic labor for which she is depending on *A*. On the trajectory from novice to expert, students pass through this gray zone. They imagine their status as 'half-baked' experts to be temporary.

While the gray zone may be a transient phenomenon from the perspective of an individual student, it should not be considered a passing, unimportant phenomenon. Not just students, but senior scientists learn continuously as well. Mature scientists will find themselves in the gray zone of 'partial' expertise as well. While having fully-fledged scientific expertise in one domain, they may have acquired some experience in other fields as well. To be an expert in one field does not mean to be an expert in a second field. Yet, it does not necessarily mean to be a complete layperson either. This leads me to the second aspect that I would like to discuss.

ad ii. Until now, I have solely considered one form of scientific expertise. I have limited myself to the kind of expertise that distinguishes a fully competent scientist in a given research field from someone who may be considered a knowledgeable scientist, but not an expert in this field. Following Collins and Evans' (2007), I call this form of expertise 'contributory' expertise in the following. Contributory expertise designates the kind of specialized scientific expertise that enables scientists to engage themselves fully in the scientific practice of a given scientific field, i.e., to perform experiments, formulate arguments, write articles, exchange views with colleagues etc. Collins and Evans distinguish this form of expertise from other forms of expertise which may be described as 'partially-enabling,' not fully-fledged forms of expertise: 'interactional' and 'referred' expertise. Both forms of expertise provide ways in which senior researchers draw on forms of 'partial' scientific expertise to compensate a lack of expertise in the field that pertains to the particular research question at stake.

In the social studies of science, Collins and Evans' notion of expertise and their distinction between 'contributory' and 'interactional' expertise have received much attention (Collins and Evans 2007; cf. Gorman 2002). With interactional expertise, Collins and Evans describe the skill to master the language of a scientific community. This proficiency is clearly important to exchange views with colleagues, but it is not enough to make substantial contributions to the field. Mere linguistic proficiency does not mean the talker is able to perform experiments and formulate original arguments (Collins and Evans 2007: 28ff.). Contributory expertise entails interactional expertise but not vice versa.[13]

13 For a critique of Collins and Evans' (2007) account of expertise and an instructive clarification of their notion of interactional expertise, see Goddiksen (2014).

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For my purpose, the concept of interactional expertise is useful insofar as it sheds more light on the gray zone between opaque and translucent dependence. One way for a mature scientist to have 'partial' expertise is to have interactional expertise of the question at stake (while having contributory expertise in a field that is not of immediate concern). For interdisciplinary research, some interactional expertise that reaches beyond a scientist's niche of specialization seems to be indispensable. A post-doc in the planetary science groups describes the issue:

> Astrobiology is a really, really good example [of interdisciplinary research] because it combines physics, geology, biology, chemistry, astronomy and you need to know a little bit about everything. And of course you have your little niche in this field, but even though you're a chemist, you still need to know something about everything else in order to be able to take what you're doing and put it into the broader perspective of astrobiology. [Laura, post-doc in physics, group 1]

Furthermore, interactional expertise can enable the scientist to transfer parts of her contributory expertise to a field that is of interest in order to make a judgment about the question at stake. Collins and Evans call such expert judgments 'referred expertise' (Collins and Evans 2007: 64). Referred expertise is expertise from another field of research that is indirectly applicable. The authors' examples of the kind of judgments that referred expertise allows have a rather 'managerial' character (Collins and Evans 2007: 66). I will, however, give you an example of referred expertise that is an internal, genuinely scientific judgment. In my interview with Adam, I asked him how he judges the competence of potential collaborators from different fields:

> Q: Ok, so what would be an example for a signal that tells you this person is maybe not competent? Not competent enough?
>
> Adam: If they are missing fundamental lines of argument, if they are confusing cause and effect for example, that would be bad. And if they are vague on something which is really quite important – and if I explain something, something that is quite basic, and they still don't get it.
>
> Q: But I can imagine that this works out nicely with another physicist, but if you are talking to another, let's say biologist, can you then be so sure ...
>
> Adam: Yes, I think mainly the arguments are the same in that they should be able to explain their thing to me in a way that I understand it. And in the way they explain it, you can tell, normally, whether they understand it themselves. [Adam, senior physicist, group 1]

Despite the fact that Adam does not possess the same expertise as his interlocutors, he can make an informed scientific judgment about them and the things they have to say by means of referred expertise. If Adam was to rely on the things they have to say for his personal knowing, he would thus not be dependent upon them in a completely opaque way.

What this discussion shows is that as concepts, opaque and translucent epistemic dependence give us useful handles on the diversity of dependence relations in collaborative scientific practice. But as a dichotomous distinction, they tell us only one half of the story. In practice, there is a large gray zone between opacity and translucency. Within this gray zone, there are clearly instances of more and less expertise. A third-year student is not yet

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an expert, but will usually possess more expertise than a first-year student. I will refrain, however, from speaking of a continuum between epistemic opacity on the one hand and translucency, or even epistemic transparency, on the other. A rationale for computing the 'opacity co-efficient' of a given epistemic dependence relation is not to be had. The issues of expertise that are entangled with epistemic dependence are too intricate. With interactional and referred expertise I have pointed out how dependence relations in the gray zone can be understood.

5. CONCLUSION

Why does a distinction between opaque and translucent epistemic dependence matter? Concisely put, a differentiated understanding of epistemic dependence matters to an investigation of trust and knowing in collaborative scientific practice, and it helps us to characterize the empirical variety of research group collaboration in scientific practice.

In the planetary science group, group members from different fields of expertise contribute to the joint pursuit of research questions. For this reason, relations of opaque epistemic dependence are frequent. Epistemic opacity can be handled, because scientists in the planetary science group have come to know each other's professional qualities during a decade of close collaboration. Furthermore, they have acquired interactional expertise that helps them to bridge between their own and foreign fields of expertise. As we have seen, interactional expertise has the potential to render dependence relations 'less' opaque.

The situation is clearly different in the molecular biology laboratory with its comparatively high fluctuation rate. Here, relations of epistemic dependence have a different character. Post-docs and senior scientists, who delegate work to doctoral students and students, will usually be epistemically dependent in a translucent form. Students, in turn, may be opaquely dependent on more senior researchers, but since they perceive themselves as experts-to-be the epistemic opacity they are confronted with is transient. As they learn to master experimental techniques more and more independently, they gain gradually more and more expertise. Much of the epistemic dependence that students are involved in is a gray-zone dependence – not opaque any more, but not yet translucent either.

To conclude, let me return to Hardwig's reflections upon epistemic dependence. Hardwig is cautious to apply this argument about the rational formulation of beliefs to the concept of knowledge itself, particularly to knowing in collaborative scientific practice. Can a scientist genuinely know that p without having evidence for the belief that p? If we are inclined to give a negative answer to this question, then we are forced to admit that 'most of our scientific research and scholarship could never, because of the cooperative methodology of the enterprise, result in knowledge' (Hardwig 1985: 348).[14] Therefore, it seems more plausible to give a positive answer. But a positive answer entails epistemological difficulties: If we take the individual scientist to be our prime epistemic agent, then we have to admit that the scientist as our prime epistemic agent often times would not possess immediate evidence for her knowing. Often, she would not have witnessed

14 Kusch (2002: 50) reformulates this thought in a more systematic manner.

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crucial experimental steps, she may not even understand them nor have the necessary expertise to interpret them.

At first glance, Hardwig draws a drastic picture of science. Yet, while he is certainly right in directing our attention to the level of epistemic dependence involved in the creation of scientific knowledge, this picture is in need of some refinement. Epistemic dependence in scientific practice is a phenomenon with more shades than Hardwig's account suggests. Hardwig's conclusions can be qualified and a more subtle grip on scientific practice is gained: Yes, epistemic dependence pervades science, but this epistemic dependence can take varying forms. Not all dependence runs deep.[15]

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