7

An Anatomy of a Microanatomy

It is Friday afternoon, and the Christmas of 2013 is drawing close. Activity at the Sea Lice Research Centre has noticeably wound down before the holidays. In one of the 3rd floor microscopy labs, adjacent to the rooms where nucleic acids are diligently being processed, we find two scientists leaning against their respective eyepieces, deeply engaged in an intense session of collaborative microscopy. Tom is a senior professor experienced in histological analyses of tissue sections, while Hanna is a postdoctoral candidate and a newcomer to the field. Trained as a molecular biologist, working with "whole" animals as her object of analysis is a rather fresh experience. It contrasts with the methods Hanna normally employs to understand the behavior of lice genes in the laboratory, where she usually interacts with the parasite at the level of gross anatomy and the molecular scale. Fascinated by microanatomy, Hanna has eagerly pursued this new gland-mapping project under Tom's guidance. They are motivated by the hope that better understanding the glandular system's organization and developmental timing in lice can offer useful insights for ongoing efforts to characterize molecular pathways involved in modulating and suppressing the host immune system.

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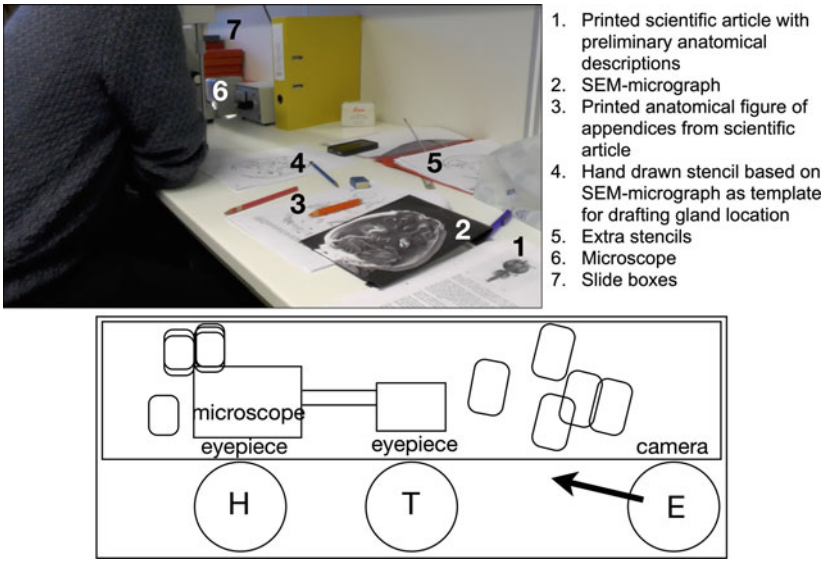

Fig. 7.1 Orchestrating representational artifacts on the bench during microscopy. Simplified birds-eye view of relevant parts in the scene, including placement of camera and ethnographer (E)

Laid out in front of the collaborators, on the professor's side, is an array of colored crayons, pens, pencils, a print-out from a photo taken with a scanning electron microscope (a SEM-*micrograph*), a scientific paper with an incomplete description of some other salmon lice glands using a whole mount staining technique, and a hand drawn stencil, based on the micrograph as its template. To the left, on Hanna's side, hidden in Fig. 7.1, are stacks of boxes containing hundreds of microscope slides of *L. salmonis* specimens.

In the moments leading up to the events in Table 7.1, Hanna has just inserted a new slide on the microscope stand and adjusted the instrument's focus to better see the specimen. The two then start scanning the slide's scene, looking for meaningful structures as their gaze shifts between landmarks on the histological landscape that is projected onto the eyepiece. By turning the microscope's knobs, Hanna can move the specimen around. Her interactions with the delicate instrument are careful; it is easy to lose one's bearings in the vast anatomical vista of a

Table 7.1 Excerpt from conversation

1	**Tom**	But what about those next to there? Is that the saliva-complex, no?	*Adjusts magnification with right hand*
2	**Hanna**	No, it is not	
3	**Tom**	But	
4	**Hanna**	They are pretty far down, now I started where we left off on the other side, or the other sections	*Moves her left hand and taps the slide box with a flat palm, three strokes*
5	**Tom**		*Taps fingers, twelve strokes*
6	**Hanna**	Because usually	
7	**Tom**	But there come three glands, or two plus a muscle, are the other big one hemolymphs?	*Waits, taps hands gently on the bench, thirteen strokes*
8	**Tom**	But is that, that one in the middle there, what?	
9	**Hanna**	Did you think of this?	*Moves specimen into focus with her right hand by adjusting knob on the stereo microscope*
10	**Tom**	Mmm, the one in the middle, what?	
11	**Hanna**	This one? I think we've seen it before, we thought it was a kind of muscle	*Moves to turn knob controlling arrow visible in the microscope's visual field*
12	**Tom**	Mhm, I just thought it did not look like much of a muscle, but I might be wrong	
13	**Hanna**	Yeah, we've tried to look at those before, but don't know if we concluded with certainty	
14	**Tom**	Yeah, but I think the one we saw, we concluded with certainty	
15	**Hanna**	Moving a bit backwards	*Removes the current slide and places a new one on the microscope's plate*

tissue slide, especially if the specimen is moved around suddenly. Also, eyes tend to tire after peering into the ocular for hours. As Tom admitted after a particularly long session, this sort of work requires a bit of "monomania" and the epistemic payoffs were far from guaranteed. In his words:

Fig. 7.2 In line 1–2 (left image), Hanna moves specimen into the center of the visual field by adjusting the knob with hand. In line 9 (right image), Hanna moves her hand from the lower knob to upper knob, to control an arrow pointer in the visual field that allows highlighting of microscopical objects

"the more you look the more nuances appear; the question is whether the nuances you see really matters."

The slow, steady pace of work also makes ethnographic observations challenging. As an experienced technician admitted, during a prolonged session in front of the electron microscope: "watching other people using the microscope is the best sleeping medicine." Unless, that is, one can maintain a disciplined and vigilant focus on the minute details of interaction between microscopists and their material environments, where meaning-making activities of deep interest to the cognitive ethnographer become visible (Fig. 7.2).

Above is a sample of what the two scientists say to each other and do to create meaning from a microscopic piece of salmon lice tissue within a time span of roughly 2 min and 40 s. Speech acts are written in plain font, while concurrent interactions in other modalities are written in cursive on the right.[1]

Overview

How do biologists, like in the interaction[2] above, arrive at shared understandings of microscopic phenomena, and jointly see them as meaningful entities? Previous chapters have looked at how representations are propagated through various representational media within the experimental system at the Centre, in ways that support new insights about the biology of salmon lice. Such knowledge does not spring from abstract sequences in a clean and tidy lab facility. They began accumulating on basis of observations of the gross behavioral repertoires of lice as they latched onto their prey. Strains of salmon lice, and their hosts, were then domesticated into new laboratory facilities. In wet labs, lice were subjected to bioassays that further probed behavior and physiology, all the way down to the molecular level with the help of RNAi and other biotechnologies. Salmon lice were physically transformed from living matter into tissue samples, and homogenates from which nucleic acids could be extracted. Later, these were converted into gene expression measurements, subjected to histochemical methods, and a variety of other representational modalities. In previous chapters, I looked closely at select examples from this experimental pipeline and described how these entities were represented, and what tools were needed to do the representing.

Here, I examine a series of events sampled from the activities of a small group of researchers at the SLRC who set out to describe the anatomical structure, distribution, and developmental trajectories of exocrine glands in *Lepeoptheirus salmonis*. In this work, insights about the secrets of salmon lice exocrine glands were acquired through the practice of "histology," anatomical studies of biological tissues with microscopes. After introducing the ethnographic context of microscopy at the SLRC, the chapter turns to some general epistemic issues concerning the acquisition of new knowledge about microscopic things. These epistemological mediations, which take Ian Hacking's work on representation and intervention as a point of departure, problematizes what it means to see and represent things using an apparently prosaic instrument.

This sets the stage for zooming in on a series of collaborative work sessions in microanatomy that stretched over a two-year period, and

mainly involved Tom and Hanna, with occasional help from other colleagues. Their mission was to map the biological landscape of exocrine glands in lice and provide a descriptive model of these structures, knowledge which was believed to be central for better understanding parasite–host dynamics. Tracking the work of Hanna and Tom as they interact with imaging technologies, I show how biological meaning is created by carefully examining and manipulating scientific visuals. As in previous parts, the methodological dictum for the cognitive ethnography is still asking the question of what information goes where, when, and in what form.

My analysis is based on participant observation in thirteen sessions of microscopy. Depending on the ethnographic circumstances like suitability, timing, respect for my interlocutors' need to focus, some of these events were audio-recorded while other segments were captured on digital video. Ethnographic observations were sampled from compound light microscopy, with additional forays into sessions involving scanning electron microscopy. Observations also covered laboratory preparations of tissue samples and the production of scientific visuals, such as *in situ hybridization*. I was also given access to drafts, notebooks, sketches, article manuscripts, and correspondences with scientific journals about the peer-review process.

In the excerpt above, we saw an example of how collaborative microanatomy, or "histology," requires participants to mutually orient their attention to the same phenomena of interest by creating spatial reference to aspects of the biological tissues at hand. Here, I demonstrate how spatial language, along with a range of other semiotic resources, enables practitioners of microscopy to mutually attend and create reference to microscopic phenomena to constructively reason about them. Through the cognitive ethnography of interactions in front of the microscope, analysis of inscriptions in laboratory notebooks, and anatomical descriptions from scientific research papers, I demonstrate how novel insights emerge through engagements with research materials and laboratory techniques. These discursive practices integrate and transform representations in ways contributing to the perception of novel biological structures and are thus a source of epistemic progress in the field of microanatomy.

Interactions between scientists and the microscope are neatly captured by Hacking's maxim "don't just peer; interfere" (1983: 189). To render their "domain of scrutiny" meaningful (Goodwin, 1994: 606), my interlocutors had to compare and crosscheck their microscopic observations with other scientific representations. These included digital media from other imaging techniques and scientific visuals produced through histochemical methods like *in situ hybridization*. Eventually, new biological meanings were created by fashioning multiple models of lice exocrine glands, bringing microscopic visuals into coordination with ephemeral language and more durable inscriptions and artifacts of various kinds. Here, my analysis builds on Alač, whose ethnographic study about fMRI-practice demonstrates how scientific visuals meaningfully orchestrate propositional language and multimodal representations to create hybrid semantic structures (2011: 144–145). When situated in the cognitive ecology of the lab, tissue sections become malleable substances and joint fields for multimodal interaction. This hybridity between language and other semiotic resources, becomes a precondition for how scientists perform, manipulate, and make sense of microscopic objects of interest.

Microscopes and Histology at the Centre

Like few other apparatuses, the microscope epitomizes the scientific instrument. Although I regularly observed staff practicing microscopy in the lab in a variety of contexts, its central role for knowledge production first dawned on me during one of the Centre's weekly lunchtime laboratory meetings. These events, which lasted up to an hour, offered an occasion for management to disseminate information about urgent matters. And although these meetings sometimes collided with time-sensitive experiments, they offered a forum for exchanging ideas and opinions about ongoing work at the Centre, presentations of novel research findings, and discussing matters of general relevance to the research community.

Outlining a program for an anthropology of knowledge, Fredrik Barth proposed that all knowledge traditions consist of "a substantive corpus of assertions, a range of media of representation, and a social

organization" (2002: 1). As social architectures that can serve many epistemic functions for the research group, lab meetings offer a microcosm for interrogating how different faces of knowledge interrelate to produce "tradition-specific criteria" for the validity, transmission, and reproduction of knowledge within a community. As Dunbar suggests, such meetings offer a most representative cross-section of the ways scientists think and reason in vivo (1999: 86). In these encounters, we can observe how scientists discuss competing models and diagrams, design and dissect experiments, examine errors, tell alternative stories and explore the feasibility of ideas. Dunbar also found that lab meetings are events where scientists freely move between analogy and metaphor, make deductions and inductions, expose unexpected knowledge gaps, determine next courses of actions, and distribute reasoning among colleagues. Laboratory meetings also highlight the germination of novel projects, and how the representations underpinning scientific breakthroughs can often have fuzzy origins. As ideas propagate, they get subjected to transformative exchanges between a cast of characters, rather than emerging fully fleshed out from the mind of individuals.

At the SLRC, laboratory meetings also served important pedagogic functions. They familiarized newcomers with the problem-space being explored, and the available means to explore this landscape. The knowledge being performed during meetings also displays the community's epistemic standards, and benchmarks for what is expected of newcomers. Such expectations were communicated through informal talk, presentations, and discussions about salmon lice biology, methods, and technique. This "hidden curriculum" of epistemic virtues serve as a guide to the research community's "moral economy" (Kohler, 1994; Mody & Kaiser, 2008). It lays out the bounds of acceptable behavior, and legitimate forms of knowledge production. While aspects of this moral economy can be rendered explicit on occasion, many dimensions are tacit and habitual, surfacing only when expectations are broken.

One Monday in early September 2013, the group gathered for their weekly update. After a general briefing by the Director about funding deadlines for the EU Horizon 2020 research program and Open Access publishing, the topic eventually turned to pressing issues concerning the staff's use of microscopes. Word was given to Tom, who was responsible

for overseeing these instruments and helped train newcomers in their use. He said that "a couple of accidents" had occurred in the lab weeks before, deserving the group's attention.[3] Among his main concerns was the soiling of an objective for a high-end microscope. An unknown perpetrator had made a mess during oil immersion microscopy, a technique developed to increase the resolution of microscopes under certain conditions. Microscopes consist of many parts, and when light passes through different materials like biological tissue, air, and glass, it is broken and bent as it travels at different speeds. Optical concepts, like the refractive index, describe how light bends and the ratio of radiation speeds. Microscopic lenses work by reconstructing scattered light. However, on very large magnifications the resolution of conventional "dry" objectives is poor, as light refracts on its journey through different media toward the eye. Consequently, it becomes hard for the viewer to separate two objects in the visual field. By immersing the specimen and objective lens in a transparent oil with the same refractive index as glass, this effect can be countered, as the microscope's resolving power at large magnifications is increased. Someone had attempted to use this oil immersion technique but applied oil on the wrong objective and without cleaning up the costly tools. Sorting this mess was exasperating work, so the next time somebody wanted to try oil immersion microscopy they would have to ask permission and get proper training. Microscopy called for a specialized craft pedagogy and legitimate practical apprenticeship.

Next, the professor lamented that their technician was overburdened by requests for tissue sectioning of lice. While researchers in other labs commonly prepare tissue samples themselves, microtome sectioning, mounting of tissue on slides, and staining was usually performed by an expert technician affiliated with the Centre. Tom announced that the research group had recently become too indiscriminate about which specimens they submitted for sectioning. When the technician had too much on her plate, the craftsmanship would suffer, he warned. Besides, many samples were likely never subjected to proper histological analysis. Meaningful scrutiny of phenotypes resulting from RNAi and gene expression profiling was time-consuming, and more sectioning was not always better. Such aimlessness was also costly and ineffective, in his opinion. Resources were being spent on sectioning tissues for no purpose

beyond storage, as a precautionary measure. Samples needed to be prioritized, as resources were finite. Unless sectioning was carried out in light of particular research questions, the Centre risked wasting its limited means. It was, in Tom's opinion, unnecessary to section controls for every RNAi experiment, and he reminded his colleagues that shared reference sections were available for comparative purposes. It was adequate to just section those biological structures that were targeted by the RNAi trial, and not the whole louse.

Tom's pronouncements spawned a lively discussion. Was the system rationally designed? Perhaps capacity really was too low? Could students learn to section their own specimens? One objection was that this craft would take too much time to master properly, as the lice cuticle tended to blunt the edge of the microtome and required considerable finesse to properly cut. Others disagreed about micromanaging sectioning requests; there was a real possibility of making novel discoveries in the absence of well-defined research questions. One professor observed that students had become so pressed for time in their research that they often "hedged" by sectioning a lot of specimens just in case they would be of use later. Other suggestions were floated. Could the Centre obtain sectioning services from other institutions, for a fee?

Although this discussion did not come to a satisfactory conclusion, reappearing from time to time, it illustrates that microscopy practice occupied a prominent role in the Centre's experimental system. Microscopes are instruments for seeing, and as Maurice Bloch suggests, the notion that "seeing is believing" has a long history, in both western intellectual life and various folk epistemologies (2008). In fact, there appears to be a preference for sight over other sensory modalities in many, if not all, societies. One reason why scientists do substantiate claims about the nature of biological entities with evidence from micrographs is because these representational media can be used for "showing and telling." This minimizes human intentionality and agency, placing more constraints on the veracity of a proposition than language alone can bring. Bloch hypothesizes that the deceitful nature of language, and its potential for lies, is the source of this widespread association: "Sight seems to offer a peep at the world as it appears to the senses, in contrast to the treacherous [linguistic] representations peddled by others"

(2008: 29). This presents a persistent challenge for scientific communities, which cultivate epistemic vigilance through an institutionalized imperative for organized skepticism. The gravity accorded to sight as the primary sense for empirical datum, for example, incentivizes deceptive uses of manipulated imagery. This has led to the emergence of rigorous guidelines concerning image integrity and processing. While adjusting contrast, color, and brightness of whole images is considered legitimate, any form of beautification, enhancing, obscuring, splicing, or elimination of specific items in ways that affect substantively the interpretation of images is considered deceptive and in violation of good conduct. Many journals have also effectuated procedures for detecting fraudulent manipulation of imagery, although there are multiple article retractions every year in molecular biology due to disagreements about the veracity of scientific visuals.[4]

Visualizing Biological Structure

Compared to the largest and smallest things in the universe studied by scientists, like galaxy clusters and the quantum realm, *Lepeoptheirus salmonis* is a medium-sized object. The size of the adult louse affords observation of gross anatomical features by careful inspection, without much visual augmentation. Adding a stereomicroscope, a sophisticated magnifying glass, affords an even better view of the well-adapted parasite at later life stages. However, many salient features of interest to my interlocutors exist on a much smaller scale. Seeing and reasoning about these biological phenomena necessitates an extension of sensory modalities, and they can only be accessed after lice tissues have undergone biochemical transformations that render properties usually invisible to a naked eye legible under a compound optical microscope. The stereomicroscope and the light microscope may look alike, but they are quite different instruments. Harnessing their powers requires different skills and background knowledge. When using the stereomicroscope, a researcher simply puts a specimen of appropriate size under the objective and peers into the eyepiece. Competent use of light microscopes, on the

other hand, requires transformative work on a much broader range of media to harness the instrument's representational properties.

To understand the logistical and epistemic challenge that tissue-sectioning presented for the research pipeline, one must grasp some basic principles of "histology," the study of normal tissue structures and how tissues are related to basic biological functions ('histopathology' is the study of diseased tissue). In contrast to the stereomicroscope, biologists cannot simply stick chunks of biological matter under light microscopes and gain much useful information just by looking through the ocular. As Hacking underscores, microscopes "does not work in the way that most untutored people suppose" (1983: 186). For microscopic materials to be informative, they must be intervened on in several ways. First, samples of relevant tissue are sampled from the organism in question. Small animals, like the salmon louse, can be sampled whole. This tissue must then be fixated to preserve affordances and maintain its structural integrity as close as possible to its live state, usually by placing it into a fixative solution, such as formalin in 10% concentration for a day or two, depending on the protocol being used.

Following fixation, the tissue is transferred to a small plastic cassette for processing and embedding. Water and formalin are removed from the sample and replaced with a solid substance that can be cut very thin.[5] While manual processing is possible, my interlocutors used a computerized device known as a "tissue processor" which could be left to run overnight. This machine is preset with programs that automatically administer reagents for dehydrating (using ethanol), clearing (chemically removing ethanol with an organic solvent), and infusing the tissue with warm paraffin wax (which is cooled), or other liquid mediums like epoxy resins (which require heating). These materials have different properties that may be harnessed depending on the histologist's interests. While resins can be cut super thin, paraffin embedding can be used when it is necessary to recover nucleic acids from the tissues after they are processed.

When infused with the medium, tissues are shaped into small blocks in special molds. These are then left to cool, usually submerged in a small tray filled with water (with a short stop in the freezer if paraffin is used). When taken out, the blocks can be cut into extremely thin sections on an

instrument known as a *microtome*. Extreme thinness is necessary so that the section is translucent enough that light may pass through the sample, about 3–5 μm. Operating the microtome requires fine motor skills and plenty of patience. A complete set of sections from a whole louse specimen, aligned in the dorsal to ventral direction, may consist of up to 300 individual sections (anterior to posterior cuts may run to the thousands, but are rare). After being carefully removed from the microtome, these delicate slices, only a few microns thick, are then floated in a water bath and left to straighten out before they are carefully transferred onto a glass microscope slide.[6] Finally, slides are placed on a tray and dried.

Although the first microscopes appeared in the seventeenth century, the work of making microscopical observations was very cumbersome (Hacking, 1981). While elites used microscopes as entertainment devices, the first aimed at a popular audience was based on ready-mounted slides for users to see anything at all; only expert technicians could use the instruments without such mounts. Hacking suggests that microscope technologies made little progress over its two first centuries, and optics did not become a branch of science before Ernest Karl Abbe, co-owner of Carl Zeiss AG, found a way to eliminate distortions in the 1860s. Despite some progress in optical theory, there was little headway in practical applications until people started staining tissues. Counter-intuitively, fresh biological tissues are almost translucent when cut thin, so placing them directly under a microscope yields little information, in contrast to the stereomicroscope.

The next step is therefore to stain slides for color and contrast. During staining, the paraffin or plastic is removed with a solvent, and sections are rehydrated. A wide range of buffered stain solutions (dyes) have been developed for different tissue types. For instance, when processing RNAi samples at the SLRC, my interlocutors would use plastic sections stained with toluidine blue. On the other hand, the principal "H&E" stain was used with paraffin sections, which consists of two counterstains that give a visually salient contrast: hematoxylin (H) stains cell nuclei blue, while eosin (E) stains cytoplasmic proteins, collagen, and muscle fibers red. Depending on the pH value of the tissue, various proteins may also appear strikingly different. After staining, slides are then either dehydrated in alcohol and treated with a clearing agent to remove alcohol to

make the tissue translucent or mounted without dehydration (the latter is often used in molecular visualization methods, like *in situ hybridization*). A synthetic mounting medium is then finally added to a small cover slip and placed on top of the sectioned tissue. The stained tissue is now protected, ready to be organized in a slide box, and further explored with the help of a microscope.

While the interactional analyses below are primarily sampled from events involving conventional light microscopes, I also observed multiple sessions with a scanning electron microscope (SEM). In the beginning of their quest, Tom and Hanna only operated this instrument with the assistance of specialists from the University's shared facilities for electron microscopy (*Elektronmikroskopisk Felleslaboratorium*), until Hanna acquired skills to productively wield the instrument unsupervised. SEM has much higher resolving power than a light microscope, which makes it possible to see whether two adjacent items are distinct objects at very high magnifications. Put briefly, the key difference between these epistemic enhancers is that a light microscope utilizes light beams for illumination and absorption of different wavelengths of light in the specimen, which are then focused and observed through an ocular. The electron microscope, on the other hand, uses an electron beam that scatters on the specimen's surface. On modern instruments, the resulting image is then reconstructed on a computer screen with three-dimensional depth of view. Scanning electron microscopy also requires specially prepared lice specimens. While having the advantage that samples can be "whole-mounted," the preparation for SEM is quite different from the thinly cut tissue sections used for optical microscopes or transmission electron microscopy (the latter yields flat, two-dimensional images of the object's *ultrastructure*).[7] Furthermore, "live" tissues cannot be subjected to SEM due to the electron beam's power (which heats the target), and the vacuum chamber (which focuses the beam, but require dry specimens to avoid water vaporization).

All innovators of novel scientific representations must persuade their peers that they denote objective states in the natural world (Gooding, 2004: 559). While Tom and Hanna used light microscopes to map internal structures, SEM was mainly used to explore the morphological

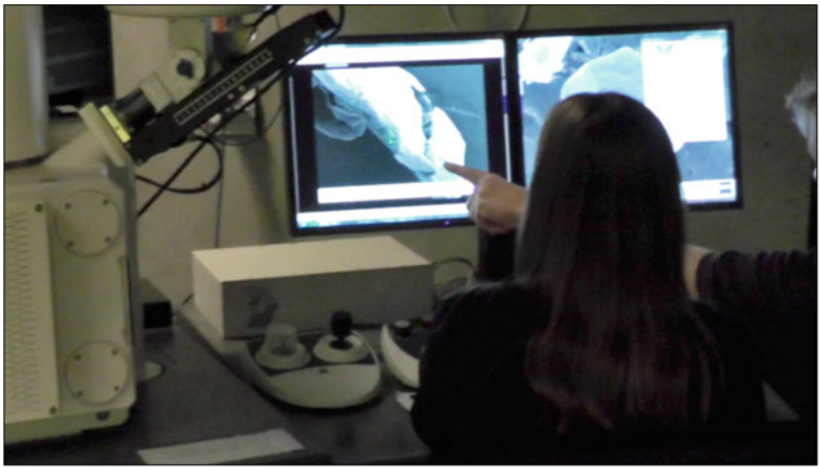

Fig. 7.3 Collaborative scanning electron microscopy of exocrine glands using whole-mount specimens. Tom annotates visuals on the screen for Hanna using deictic gestures

features of the parasite's outer surface, and to produce sharp three-dimensional images. As Tom explained in one session with the electron microscope, the main purpose of a future publication on this topic would, after all, be to showcase their observations of the lice exocrine system. Although no scientific representation is self-explicating and can speak for itself without a culturally elaborated coding scheme (Goodwin, 1994), a key ingredient in telling a scientifically interesting story about this system was annotated imagery that clearly and persuasively highlighted discovered structures to their peers. By observing the organism's exterior through the high-powered electron microscope, it was possible to get a holistic overview and collect data about novelties which could mutually corroborate their results from light microscopy (Fig. 7.3).

Exocrine Glands

Glands, the objects of scrutiny in Hanna and Tom's project, are biological organs composed of clusters of cells specialized for making substances

that the cells themselves have no need for, but are central for extracellular processes. Products of glandular organs are either released into the hemolymph, a fluid analogous to blood in vertebrates, and internal cavities. They may also be transported to the parasite body's outer surface through exit channels (although these may also be adapted for internal secretions). In the first case, the glands are classified as *endocrine glands*, and in the second case they are called *exocrine glands*. Their motivation for working on exocrine glands was twofold. More knowledge about the body plan and biological organization of salmon lice would be an asset for much experimental work, since functional macro-physiology provided an interpretative resource for molecular and computational analyses. Another motivation was the need for a detailed account of how exocrine glands in blood-feeding parasites produce substances that are secreted to the outer host environment. By investigating these glands and their anatomy there was also a slight chance of identifying potential therapeutic candidate genes that were highly expressed in these organs.

As Tom, Hanna, and colleagues argued in a draft manuscript on the subject, these glands "may secrete substances that modulate the immune response of the fish and limit clotting of blood from the host during feeding." Knowing where and when certain genes were expressed, could not only help resolve *structural* questions about the involved mechanisms, but also provide *functional* answers about how host interactions are regulated. This, in turn, could usefully inform therapeutic applications down the line. Work of this kind required fitting microscopic data to evidence from molecular biology, so that structures observed in the microscope could be individuated by their biochemical properties. Vice versa, these molecular data would ideally be interpreted in the light of macro-biological structures and processes, creating an interlocking fit between different levels of analysis (Fig. 7.4).

According to Tom, investigations at the molecular level were frequently launched in the absence of well-grounded models of higher level anatomical structures, where the purported molecular processes were assumed to unfold. As he expressed with some disbelief; some of their more molecularly oriented colleagues were not even aware that the structures they now dedicated time to meticulously describe were *glands*. They were simply referred to as "sub-cuticular tissue" in the literature.

Fig. 7.4 Slide boxes with stained lice tissues. Each slide is numbered and chronologically organized from the first to last section. This facilitates easy location and retrieval of relevant points of interest

Thus, researchers needed "a vocabulary" to describe what they saw, in his opinion. He considered the language of microanatomy to be "a language of its own." Detailed models of molecular pathways were not sufficient to make sense of the biological complexity of these organisms. Previous research on lice glands by others had only resulted in a rough draft of the topology and organization of structures like the frontal filament, its mucus-producing glands, and some pores and exocrine glands specifically located around the parasite's mouth tube. Additionally, there was some documentation of glands in the cephalothorax region and its genital segments. Previous attempts at whole-mount staining of the animal had only visualized the largest glands and revealed precious little functional information about the mechanistic nature of these structures and their classification. Arthropods have a complex segmented body plan with many joints and appendages, which become an immense and vast landscape under the microscope. Time and technical constraints therefore restricted the scope of Hanna and Tom's investigation to the head, the thorax region (*cephalothorax*), and thoracic limbs.

Contemporary life scientists primarily aspire to give mechanistic accounts of how biological systems operate (Bechtel, 2006; but see Myers, 2015 for a contrasting perspective). Tom and Hanna, for instance, wanted to craft an anatomical account of the structural relations between the different parts that constitute the louse exocrine glands, both in terms of the glands' spatial contiguity and the functional organization of different components within the larger system. As Bechtel points out, the preferred strategy of mechanistic explanation in biology requires both *structural* decompositions, by taking structures apart into their component parts, and *functional* decomposition, by looking at how the components operate in concert (2006: 31). While the microscopic journeys explored in this ethnography primarily concerned the structural decomposition of the exocrine system, this structural information could yield functional insight into the operation and orchestration of component parts, especially when coupled with molecular evidence.

The Scientist's Microscope and the Blind Man's Stick: Theory and Technique

What kind of cognitive artifact is a microscope, and what epistemic actions does the use of one entail? As popular icons of scientific practice, it is easy to imagine that you can just peek into the eyepiece and that a new, micro-sized landscape will open in front of your eyes. But while microscopes appear deceptively simple, as Hacking stressed, the scientific uses of this device are complex, multimodal activities, quite different from everyday notions of what it means "to see" something. This first became apparent to me, as I one day was sitting by the workbench next to Hanna, observing her microscopy work through an extra ocular on her instrument. As I was tracking her activities early in my study, she suddenly notified me that she was observing "interesting things". But although I was trying hard to see what she was saying, the tissue only appeared as homogenous mush to me. I realized my lack of crucial skills and concepts for making sense of what undoubtedly was there, somewhere in front of my very eyes.

Scientific visuals can sometimes be the starting point of an investigation, and at other times its endpoint. As such, they play an epistemically prominent role in both what philosopher Hans Reichenbach called "contexts of discovery" (i.e., the generation of novel ideas or hypotheses), and in "contexts of justification" which concern their defense, test, and verification (see Schickore & Steinle, 2006). To acquire epistemic status as evidence within any given research project, tissue sections must be subjected to considerable interventions. Acts of visually inspecting and reasoning about biological samples via the microscope also require human–instrument couplings that delegate some cognitive processes beyond the human investigator. As malleable materials, scientific visual must be transformed and manipulated to support reasoning. They are not just disembodied data resources for thinking about phenomena, but stuff that scientists think *with*.

One lesson from studies on the interplay between visual representation, instrumentation, and the perception of scientific objects we cannot ordinarily see, is that the couplings between scientists and their representational tools may take on surprising forms. To conceptualize such

couplings in terms of a cognitive ecology, Ed Hutchins invokes a thought experiment from Gregory Bateson, then inspired by the nascent field of cybernetic systems and regulatory feedback loops (2010: 706). Bateson asks us to imagine he is a blind man who taps around with his white cane: "Where do I start? Is my mental system bounded at the handle of the stick? Is it bounded by my skin? Does it start halfway of the tip of the stick? But these are nonsense questions. The stick is a pathway along which transforms of difference are being transmitted. The way to delineate the system is to draw the limiting line in such a way that you do not cut any of these pathways in ways which leave things inexplicable. If what you are trying to explain is a given piece of behavior, such as the locomotion of the blind man, then for this purpose, you will need the street, the stick, the man, the street, the stick, and so on, round and round" (1972: 459). His message is that prematurely demarcating the boundaries for our unit of analysis may hide central resources that emerge from mutual dependent relations among elements. By widening the notion of epistemic processes to include the exchange of representations between scientists and their situated environment, we can better account for the nature of such couplings. While the notion that "everything is connected" may be a truism, science still depend on exploiting nonuniformities among elements in different systems, and since Plato it has been a general principle of scientific inquiry to "carve nature at its joints" (Hutchins, 2010: 705). Articulating the world in a scientific manner, usually means looking closely at sites where there is low connectivity between things. This requires accurate representations of the world, including its unobservable parts. If we want to understand how microscopes and other instruments contribute to meaning-making, we must look closely at scientist–microscope assemblies as coupled systems. The microscope is to the scientist, as the stick is to the blind man.

Here, it is tempting to reach for analogies between a microscope's power to reveal the unseen, and visual aids like reading glasses. But like other imaging techniques, such as fMRI scans (Alač, 2011) and X-ray protein crystallography (Myers, 2015), microscopes do not afford views of the very small with the same ease as when we assess the weather by looking through a window, or put on a pair of glasses to read tiny print. Such analogies are deceptive and misleading.

It is, however, true that microscopes, like the blind man's stick, are interfaces that can become "transparent equipment" that works effortlessly for the user, with adequate training (Clark, 2008: 34). So, in what sense then is the act of seeing something with a microscope distinct from using a pair of glasses?

Well, let us again do some imagining. We train a chimpanzee with poor eyesight to wear glasses and examine a cluster of bananas at some distance, so the appropriate glasses help our chimp to better see the bananas, just like a human with poor vision can better see the fruit using the right spectacles. Now, we make the chimp and human layperson to peek into an eyepiece on a microscope that projects light through a stained louse section. Neither is familiar with microscopes or modern cellular theory. Would chimp and human see the same things? Well, since the projections to each species' receptor cells are fairly similar (both have trichromatic color vision), the difference between what they "see" in a restricted sense is likely not very different, and the scenery is unlikely to appear meaningful. However, switch out the layman with a properly trained biologist, and the human would see a different landscape manifest itself. Competent use of microscopes requires an arsenal of discursive practices, and the histologist would come equipped with conceptual coding schemes and practical resources for interacting with the device and construct meaning from what appears. Together, these resources constitute an actionable "professional vision" for probing the specimen (Goodwin, 1994), and the histologist can meaningfully articulate and engage what is being projected to her retinas. In what Michael Polanyi called the "tacit faculty" (2005: 105), sense perception, thought and articulation stands in an asymmetric relationship.

So, given that microscopes challenge everyday notions about what it means to see something, how does this seemingly mundane artifact help scientists achieve accurate representation of the world? Hacking clarifies this question, which he believes presents such a compelling argument for "medium-size scientific realism that philosophers blush to discuss it" (1983: 186–187). His first illustration comes from a former president of the Royal Microscopical Society: "There is and there can be *no* comparison between microscopic and macroscopic vision. The images of minute objects are not delineated microscopically by means of the ordinary laws

of refraction; they are not di-optical results but depend entirely on the laws of *diffraction*." Hence, the perceptual niche of microscopy is *sui generis*, as the view of a specimen is based on a synthesis of diffracted light rays, rather than "normal visual physics." In this context, talk of "seeing" in the ordinary sense is quite misplaced, bordering on a category mistake. This impreciseness is not due to a lack of correlations or fidelity between projections on the retina and what lays below the lens, but simply because the physical process of creating images with a modern microscope is not the same physical process that unfolds when we perceive something with a naked eye. What we usually see around us is a consequence of reflected light, but when peeking into the microscope we perceive a transmission or absorption of light traveling through very thin slices of tissue captured on glass slides. Dark or light areas correspond to the amount of light transmitted or absorbed. In a microscope, light is spread apart, so it appears to be emanating from a larger object than what is actually on the plate, and light scattered by the examined object is then reconstructed for the viewer who peeks through the ocular. Different microscopy technologies can exploit very different physical principles, far away from the domain of unaugmented human vision.

In contrast to a *sui generis* notion of microscopic vision, Hacking adds a different textbook conception where the microscopic image is said to instantiate a map of interactions between specimen and imaging radiation (Hacking, 1983: 190). This view appears to imply that microscopy is somehow a theory-loaded activity, where background theory is necessary to elucidate a map-like structure. To this Hacking objects. Microscopy is not "theory-loaded" in the sense that one needs theories of optics to successfully use the instrument. Theories are certainly necessary to *make* good microscopes but *using* them simply requires practice. So, while theory might explicate physical principles behind functional tools and help mitigate distortions, including *chromatic aberrations* (deviations caused by wavelength differences in light) or *spherical aberrations* (smearing of the object due to lacking focus of light rays near the lens' edges), competent practitioners can also learn to discount such issues through trial and error learning.

But although microscopic observation is not theory-loaded by necessity, neither is it entirely devoid of theory, as the practice has co-evolved

with conceptual systems like modern cellular theory. This body of supporting resources for sense-making offers detailed models of biological mechanisms and pathways, which help to articulate distinct entities with different shapes, properties, and variations. Since organismic materials are transparent and uniform regarding light absorption in microscopy, we saw that tissue sections had to be stained with dyes to enhance their legibility. This transformation is crucial for turning tissue slides into a meaningful structure, as the staining introduces salient bits of information through what Bateson called "differences which makes a difference" (1972: 315). Knowledge about how preparations of tissues affect their visual properties further illustrates how theory can be a meaning-making resource. As Hanna and Tom taught me during one of our sessions: since the use of solvents during the staining phase of tissue preparation changes the appearance of a section, the resulting patterns can support inferences about biological functions.

Importantly, some meaningful patterns could be used as discriminatory markers to distinguish between different types of glands. For instance, a working assumption was that if glands displayed differentiated patterns of extracted fat (characterized by tiny beads) or showed vesicles of radically different sizes, the glands did probably not produce the same content, and likely served different biological functions. In one type of gland being examined, salient patterns were found accumulating around its exit channels, in another, smaller and evenly dispersed patterns were located around the cytoplasm. In yet a different case, the glands under scrutiny were identified as potentially being multinucleated cells (*syncytia*), structures seemingly packed with secretory vessels. For a while, my teachers also hypothesized that there was a difference in the size of certain gland structures between starved specimens and lice that had been fed before sectioning. The assumption was that when lice fed on their hosts, they also produced and excreted substances that modified the salmon's immune response, which would alter the visual appearance of those glands.

Theoretical knowledge could also serve as a scaffold for deciding whether certain observations were "artifacts," anomalies due to processing errors like folding, tearing, and crushing, or biologically salient. During one stretch of electron microscopy, my interlocutors used

what they referred to as "the fat-test" to resolve whether an observation was an anomaly stemming from tissue preparations, or something of biological relevance. Solvents used for preparation of specimens would occasionally fail to extract all fat molecules from the sample. In cases of ambiguity, it was possible to focus the electron beam at the suspected artifact and increase its power to 15 kilovolts, thereby causing any remaining fat to be energized and crack the gold–palladium coating enclosing the specimen. Consequently, conduction in the specimen was reduced, which manifested on the screen as halos or smears. The cultural evolution of such techniques for discounting artifacts is central to the epistemic resolve of these instruments (Bechtel, 2006; Rasmussen, 1993). In microscopy, theory and practical technique have thus come to mutually support each other (Pitt, 2011: 191), to the extent that it is now possible to automatically censor noise and even reconstruct lost information in digitized micrographs using imaging software. It is the ability to mobilize this rich set of internal and external conceptual resources to construct meanings from what appears through the eyepiece, that sets a competent practitioner of microscopy apart from the chimp and untutored human.

Questions about observational realism with respect to what microscopes can reveal, thus largely hinges on the semantic issue of what we mean when invoking the verb "to see." While the antirealist would be skeptical about its utility in the context of microscopy, a pragmatist position suggests this word should be of little concern. After all, it is already put to good use to describe entirely intellectual pursuits with little reference to visual perception, as exemplified by statements like "I see what you are saying" (see Alač & Hutchins, 2004 for an intriguing ethnographic example). As Pitt observes in an essay "on the epistemology of the very small," the verb "to see" has changed meaning many times over, as new technology has become available to us (2011). Consequentially, ordinary language use has been modified in such a way as to disregard distinctions between augmented and unaugmented sight, so that it now works as an extended metaphor in the context of many different technologies for visual support. Furthermore, despite that the eye, rather than the embodied mind, is widely seen as the primary locus of perception (Hacking, 1983: 169), scientists do not accept the veracity of what they

see solely on basis of theoretical beliefs. Hacking, for instance, defends a realism of microscopical observation with reference to scientists' material engagements with their thinking tools. First, they can manipulate things under the microscope, to gain new perceptual skills in the process. Secondly, it is possible to craft microscopic entities with the same properties as things that can be observed without visual augmentation.[8] And third, different technologies for microscopic vision may display the same phenomena, dismissing the possibility that they are artifacts of any single instrument, or that observations are overdetermined by theoretical presuppositions.

As such, what counts as seeing and observing in the laboratory sciences today entails a liberal extension of what it means to see something. It is "a long way from the eye" since we do not see *through* a microscope, but *with* it (Hacking, 1981). Competent microscopy requires learning how to use it properly, like the seemingly trivial habit of not focusing with the eyes, but to instead manipulate the physical settings on the instrument to sharpen the image. This includes the acquisition of a highly specialized vocabulary for conceptualizing spatial relations between biological structures. To exercise this professional vision, biologists' apply schemes for coding, highlighting, producing, and articulating material representations in a domain of scrutiny (Goodwin, 1994). This includes familiarity with standard interpretations, the properties of dyes, and knowledge about cellular theory, as well as specialized insight in domains like salmon lice biology, embodied by scientific texts, diagrams, and other peers. While it is certainly possible for individual scientists to productively use the microscope, the achievement of "seeing" meaningful structure in microscopic tissues should be understood as a social accomplishment.

A key output from microscopy is malleable visual representations. As such, the act of "seeing" something as meaningful biology also includes manipulation and inspection with the hands and other sensory modalities. External representations in the form of scientific visuals, such as micrographs, afford the possibility of shared "thought-objects" which can assume multiple epistemic functions through embodied interactions (Kirsh, 2010). Not only do thought objects allow material media to be reorganized, they also create physical persistence through time, so that

perspectives and relations can be explored from different vantage points. Furthermore, thought-objects make it possible to reformulate ideas and render them explicit by recoding information in different formats. Encoding insights in other material media in turn enables use and reuse of representations for additional purposes, through actions like superimposition of media, transformation of structure, and novel opportunities for additional tool use. The digitization of photographs taken with the microscope, micrographs, offers a simple illustration. With micrographs it is possible for the same image to exist in analog, durable form on printed paper, as a digital representation manifested through projections on a computer screen, and as a fleeting representation animated through gesture and talk-in-interaction. These scientific materials invite different semiotic interactions when "lodged" in a community of practice (Goodwin, 1994: 67), and can be orchestrated on the benchtop alongside other media to propel inquiry forward and reveal new epistemic things.

Clearly, scientific visuals cannot be conceptualized as static representations if we want to understand how they work in epistemic activities (Alač, 2011; Myers, 2015). Instead, they must be approached as thought-objects in motion, co-produced through representational technologies that mediate between embodied social interaction, material culture, communication, sensory perception, and visual inference. Microscopy may, on the surface, seem like a trivial technology, but on closer scrutiny its enactment raises deep questions for the anthropology of knowledge, and is therefore "good to think" (Lévi-Strauss, 1964: 89).

Establishing Spatial Reference During Microscopy

As we saw in the introductory vignette, Hanna and Tom's microanatomical observations were motivated by a set of spatial questions about the location and extent of exocrine glands, biological structures believed important for regulating parasite–host interactions. "Space", whether we are talking about the microanatomical domain or entities at the

human scale, is not a restricted domain like color, kinship, and ethnoecological classifications (Levinson, 2003: 64). These are spheres of life where anthropologists have asked and found clearly delineated and systematically encoded linguistic distinctions. Molecular parasitologists conducting microanatomical investigations, must regularly direct the attention of their peers to establish mutual reference toward things located in multiplex histological landscapes. Establishment of common ground and shared intentionality through spatial reference in microanatomy is, in turn, a precondition for evaluating scientific claims, and for achieving consensus about biological questions. For two agents to even disagree about the nature of a particular scientific claim, they should ideally be mutually attending to the same things in the world.

Cultural variation in spatial representation has been a topic of great interest in recent psychological and cognitive anthropology. As Stephen C. Levinson puts it, our knack for spatial thinking is ubiquitous. Our ability to transform nonspatial problems into spatial issues appears as "one of the fundamental tricks of human cognition" (2003: 16–17). The disposition to transform certain problems into spatial form is exemplified by diverse diagrammatic traditions and spatial schemata found across cultural contexts. This pervasiveness raises the question whether there is a computational advantage to using spatial models for thinking, since people have an almost compulsive tendency to visualize relations and problems in spatial form. Citing Levinson, again: "If humans do in fact convert problems into spatial models for this reason, then we can readily see the efficacy of diagrams, graphs, tables and the like: a picture can be worth a thousand words because a spatially presented problem can be more readily translated into spatial thinking – it is already as it were in the right format […]" (ibid.).

In technology-saturated environments like the lab, participants in an epistemic activity have many cultural protheses at their disposal to establish spatial reference and draw attention to things in their vicinity through interlocking social actions (Hindmarsh & Heath, 2000; Koschmann et al., 2011; Streeck et al., 2011). Spatial reference in both scientific and everyday contexts makes use of "construal operations" (see Croft & Cruse, 2004: 46, for a useful typology). According to the continuity hypothesis, the cultural practices of science are partly based on

mundane linguistic operations of construal that structure experience, conceptualizations that manifest in public language as a reflection of more general processes for meaning construction. Laypersons and scientists alike use public language, and other communicative modalities, to highlight and bring attention to relevant parts of their spatial experiences. In contexts of scientific reasoning, these operations can be harnessed for epistemic uses in a myriad of ways. They are also associated with specific expectations and standards among professionals. As Hanna and Tom oriented themselves toward the morphology of lice, they organized thought and action to meet the requirements of each encounter by mobilizing a variety of linguistic alternatives to grammatically encode relevant objects and events. These "online" processes for conceptualizing events, readily encodable in language, exemplify what Slobin calls "thinking for speaking" (1996).

Making scientific observations with microscopes entails taking different perspectives toward interesting phenomena in a complex work environment. Successful cultural transmission of these scientific findings usually require that observational claims be supported by data, a heterogeneous category that lumps together many kinds of cultural representations. When aggregated and situated in the context of specific scientific questions, about microanatomy, for instance, these representations may acquire status as "evidence." Scientists use language, alongside a variety of representational media, including photographs, diagrams, tables, and graphs, to articulate, scaffold, and externalize such observations.

Public language figures prominently in these collaborative interactions by helping scientists to focus their scope of attention on specific selections of the world, making spatial conceptions accessible to each other. These external thought-objects also enable adjustments in scope, making them fit with coarser and finer scales as needed. Public language does not construe a static spatial world but can draw dynamic attention to selected aspects by imposing causative semantic categories like fictive motion and force dynamics. In turn, sequences of events may be framed as scripts for action. Language also provides resources for comparisons between figure and background, forming judgments, categorizing experiences, and supply metaphors to highlight contrasts between source and target domains. By framing observations through public language,

microscopists may also conceptualize part–whole relations, individuate phenomena, and articulate topological and geometrical associations in a scene.

As observations with the microscope are situated, practitioners rely on public language to create deictic pointers that support perspective-taking and focal adjustments to objects of interest. By assuming novel viewpoints, scientists can use these referential meanings to accommodate the views of their conspecifics and organize space in ways that help disambiguate meanings through mutual orientations toward the same objects. In turn, perspectives may be articulated as to accommodate the presence of other agents in the communicative event, thereby creating common ground between speakers and addressee. Deictic demonstratives make it possible to establish reference relative to who or what is acting in each epistemic event. Time-reference in public language also enables scientists to define things relative to situations, turning time and place into deictic centers for attention. This way, abstract entities can be rendered manifest, as things to be pointed out, in the literal sense of the term.

In the context of practicing microscopy, we can usefully see such linguistic constructs as "new layers of material structure in an already complex world" (Clark, 2006: 373), which are produced not simply due to their communicative effect, but as "parts of self-stimulating cycles that scaffold their own behavior". Keeping in mind these diverse features of how language and other semiotic modalities individuate aspects of the world, let us now look at situations where spatial reference is coordinated in the quest to anatomically map exocrine glands in salmon lice. Following the methodical mantra of "what information goes where, when and in what form," I ask how mutual reference is accomplished when the world one is orienting to is only accessible with a microscope. What kind of transformations of representational states and media are required to support microanatomical reasoning?

For histologists like Hanna and Tom, tissue slides are the key media delineating their "domain of scrutiny" (Goodwin, 1994), as it is here that glands first become manifest. Notably, the slides have a "dual" status in their work. In one respect they are specially prepared pieces of individual lice specimens, but they also serve a representational function with respect to the parasite's biological constitution more generally. As

we saw, accessing this domain is not straightforward, as tissue sections undergo many preparations that render visible its features in the form of a bewildering variety of odd forms, shapes, and colors. These scenes must be decomposed so that meaningful biological structures can emerge. To individuate relevant features of exocrine glands with the microscope, Hanna and Tom had to cultivate an ability to relate structure and form to function, and achieve a perceptual alignment between eyes, hands, and concepts.

Key to the success of widespread cultural-cognitive systems like the observer-microscope assembly are "normative patterned practices" (Menary & Gillett, 2016); patterns of activity spread across multiple agents and which operate at social, individual, and sub-individual levels to govern brain-body-niche dynamics. In the excerpt from the chapter's beginning, we saw how zooming in and out, adjusting the instrument's focus, as well as moving and repositioning the specimen at the right moments helped Hanna and Tom to see and attune to the same anatomical structures. But in addition to these skilled, sensory-motor operations, competent histologists must also partition observable space via concepts by engaging in verbally mediated interactions with their peers. Through the use of linguistic and conceptual resources available in the biological community, canny cognizers acquire the competency to relate what they see in the microscope to the world by building and manipulating information structures in public space, including shared linguistic content and material structures, which can be jointly elaborated through narrative dialogue (Menary & Gillett, 2016: 3).

In Hanna and Tom's case, these normatively patterned practices of microscopy were acquired by the novice "sitting-with-Nellie"-style, a type of co-participatory arrangement that has long been of interest to ethnographers of cognition and learning (Ellen & Fischer, 2013; Lave & Wenger, 1991), including apprenticeships in science (Alač, 2011; Mody & Kaiser, 2008).[9] Initially during my ethnographic inquiry, Hanna often sat by the bench next to the professor, who guided her practices and attuned her professional vision by highlighting objects of interests. This guidance introduced new coding schemes that Hanna could use to "circumscribe and delineate the world" (Goodwin, 1994: 608), essential

tools for domesticating her perception through shared schemes so that disparate events became "equivocal observations."

Within this category of action, apprenticeship training is characterized by active exploration, with less emphasis on direct, formal instruction. Hanna would practice her craft alongside the experienced old-timer Tom; observing, participating, and asking questions while also replicating procedures and techniques independently as the context of learning gradually transitioned to one of discovery.[10] One important part of their framework for participation was "corrective practices," a type of exploratory inference that proceeds through action looping via the environment to correct future actions (Menary & Gillett, 2016). In the vignette at the beginning of the chapter we saw how this iterative, actionable bootstrapping process unfolded. In the excerpt (7.1), Tom drew attention to a structure he was ambivalent about how to classify. Hanna, in turn, suggested that what they attended to was unimportant muscle tissue; they had previously investigated it, and she believed they should explore other anatomical entities instead. However, the apprentice was not completely confident in her own conclusion and entertained the possibility that she had failed to appreciate its importance, saying: "Yeah, we've tried to look at those before, but don't know if we concluded with certainty?". They did not proceed to investigate other locations on the slide until Tom concurred with Hanna's interpretation and verbally articulated an epistemic update of the situation, thereby transitioning the coupled system of humans and microscope into a new cognitive state.

In both gross anatomy and microanatomical work, the location of salient biological objects is disambiguated by dividing biological space into subregions, and then partitioning subregions into more fine-grained segments. By using positional terms from everyday language, and specialized terminology referring to the organism's "standard anatomical position," histologists can identify relevant phenomena and carve anatomical landscapes into fine-grained parts. Special purpose anatomical jargon avoids confusions that may arise due to imprecisions and helps to resolve between conflicting interpretations of phenomena. But as we shall see, practitioners of microanatomy use a variety of additional cognitive resources beside anatomical terms of location to fulfill epistemic actions.

Like other bilateral animals, the body plan of *Lepeoptheirus salmonis* is described as segmented. It has a distinct front and backside. The front is the direction faced by its key organs of perception, and the part that arrives first during normal locomotion. Its body also has a top and a bottom (the area that attaches to the fish). Like other objects with a front, back, top and bottom, the organism is ascribed with two lateral sides. Biologists capture such invariances with specialized shop talk that identify biological phenomena as they are located and extend through physical space. Conventionally, these descriptors are mainly oriented along three hypothetical and intersecting planes.[11] The frontal/coronal plane divides the organism into a dorsal–ventral axis (back-front orientation). A sagittal/longitudinal plane forms an axis that divides the body into left and right sides. Finally, the transverse/horizontal/axial plane defines a cross-section between the superior (upper) and inferior (lower) parts. These anatomical planes specify polar pairs of locative items; each term has a counterpart with an opposite meaning, such as *dorsal* (upper surface/back) versus *ventral* (toward bottom/belly), and so on, relative to the plane in question.[12] Biological objects can be described as positioned along these planes, and by drawing on this idealized model, biologists can fashion "neutral" spatial descriptions that are meaningful without access to the same situated semiotic resources that were available to the microscopists who crafted the description.

Despite the centrality of spatiality for thinking and action, it is generally believed that humans cannot represent spatial scenes any way they like, since different linguistic systems structure the available scenery (Levinson, 2003). Usually, a portion within a scene is marked out for a primary focus and is characterized with reference to a second, and occasionally a third object. Here are two examples of constructions in Hanna and Tom's work, from a draft report on the anatomy of exocrine glands in lice:

1. "Teg 2 glands are always located in close proximity to a teg 1 gland."
2. "The pores are found anterior on the exopod distal segments (Fig. 3F), while on the thoracic leg 2 endopod they are located at the margin between two of the distal segment pinnate seta."

Table 7.2 Relative properties of figure and ground constructions, based on Croft and Cruse (2004: 56)

Figure (referent)	Ground (relatum)
Spatial properties to be determined	Location known
Smaller	Larger
More moveable	More permanent
Simpler	More complex
More salient	More in the background
More recent in memory	Earlier on scene/in memory
More dependent	More independent

These spatial descriptions belong to one of two classes of structures known as figure or *referent* ("Teg 2 glands," "pores"), and ground or *relatum* ("exopod distal segments," "thoracic leg 2 endopod"). Table 7.2 shows relative differences between these.

In the example above, the structure labeled as "pores" are contrasted to the larger and established "exopod distal segments." Briefly, a Figure is the object to be located, for instance, a moveable object whose location, orientation, or direction (path) is in question. The Ground (or "relatum") on the other hand, is the object used to identify the Figure's location. Ground is often stationary and may also be used to define direction or orientation vis-à-vis the Figure. These spatial descriptions help focus attention on smaller parts of a larger field and to determine asymmetrical spatial relations between the Figure and Ground. In contrast to metaphor and analogy, which depend on similarities for their cognitive effect, the Figure–Ground relation emphasizes contrast and difference. Additionally, modifiers like proximity and distal contrasts (nearer/further away), as well as dimensionality contrasts (bigger/smaller), may be used to specify locative descriptions in spoken language. During salmon lice microscopy, the role of Figure (referents) and Ground (relatum) was ascribed to different biological entities such as glands, channels, exit ducts, and a variety of landmark tissue structures that appeared in a histological scene as seen with the microscope.

"Where"-questions about the location of things are primarily answered in two very different ways and it is now generally accepted that all known languages accomplish spatial reference by a combination of non-angular and angular specifications. In the non-angular case, the strategy

is to "choose a ground or landmark object in close contiguity with the object to be located" (Levinson, 2003: 67). Spatial descriptions of this variety can be based on three different operations. The first kind is the familiar use of *placenames*; a Figure is located at named place G (Ground). A second construction is known as *deixis* (Greek for "pointing").[13] Deictic reference, such as "it is here," belongs to a class of complex communicative acts where receivers of a message must know about key, extralinguistic circumstances for the communicatory act to be perceived as meaningful. In these constructs, a Figure is located relative to Ground (often the ego) using radial categories ("here"/"there"), or by pointing gestures that use hands, eye-gaze, or other embodied modalities. Such acts create a special ground or landmark. This semiotic resource, deixis, exemplifies deep entanglements between language processing and context, what Levinson describes as "a big black fly in the ointment" for disembodied theories of language (2008: 97).[14]

The third kind of non-angular operation is known as *contiguity* or *topology*. In this construction, the Figure is located contiguous with Ground. In English and Norwegian this is accomplished through prepositions that mark spatial coincidences like proximity and contiguity, containment, coincidence, and the like, for example, subdivisions such as *on*, *at*, *in*, *between,* and *such*.

In addition to these three non-angular constructions, spatial reference is also achieved using a second class of angular constructions. These locative constructions mark out a prominent ground object away from the Figure or object of interest, and then provide a "search domain from the ground by specifying an angle from that landmark" (Levinson, 2003: 67). Here, Figure–Ground relations can become components in more complex coordinate systems. These systems construct an orientation space that identify spatial relations between objects in a scene through a coordinate system of intersecting axes across the horizontal and vertical dimension. It uses one among three unique spatial "frames of reference" that operate across natural languages: the relative, intrinsic, and absolute. In Norwegian and English, the working languages of my interlocutors, it is possible to use all three frames, but some languages

manage without all three. Note that in Norwegian and English, the absolute frame of reference is mainly used for the topographic domain ("the fish farm is *north* of Bergen"). It will not be discussed further here.

Relative, intrinsic, and absolute reference frames are differentiated by how they construct the origin-center of the coordinate system and its orientation. Common to all, is a minimally required specification of an object to be located (a Figure), its Ground (which the Figure refers to), and the origin and orientation of the said coordinate system. While frames of reference can be conceptualized independently of language, they become apparent when triggered by utterances. As Levinson observes, the difference between angular and non-angular forms of spatial reference is complicated, as the relative frame of reference also provides a conceptual schema for interpretations of spatial deixis, the second item in the non-locative class. The use of deixis through demonstrative pronouns such as *here*, *there*, *this*, *that,* and so on, establishes a form of joint attention by marking a central spatial viewpoint within the speech situation known as the *deictic center* (or *origo*), from which the coordinate system should be understood. In language interactions between competent speakers, this deictic center may continuously shift between the participants, and the use of demonstratives is usually accompanied by pointing gestures.

Traveling Through Histological Landscapes

Microanatomical studies of salmon lice rely on spatial description to answer "where"-questions by utilizing a combination of angular and non-angular locative resources. Due to the nature of anatomical practice, which requires scientists to interact closely with two-dimensional material media like tissue sections, it is variations on the first locative class that will mostly concern us in the remaining analysis. First, we look at some thick ethnographic descriptions that flesh out how Hanna and Tom create biological meaning during microscopy by transforming spatial representations while they actively explore and reason about the internal lives of lice. Later, we revisit the object-centered, intrinsic frame of reference, to examine how this form is used as a resource in

a scientific manuscript for making spatial descriptions couched in the special purpose language of anatomy to pinpoint the spatial properties of exocrine glands.

Again, we encounter Tom and Hanna at work tracing exocrine glands and other biological structures that reveal their presence, like the channels transporting substances from glands to other anatomical locations. This time they are sitting in a new microscopy lab, working on a recently acquired microscope of considerable sophistication. Like in the first montage, the two are oriented toward the instrument, with the tissue sections held in place by clamps on the microscope stage. Preferably, tissue slides are always aligned with the "standard anatomical position," which makes mappings of landmarks along the axial planes convenient for the viewer and facilitates easy comparisons with external diagrams like anatomical sketches. In contrast to the first montage, where both observers had access to separate oculars, Hanna is the only one who intermittently peers into an eyepiece here. Eyes are mostly fixated on a screen projecting a cable-transmitted image from the microscope-mounted camera. This makes it possible for both investigators to orient and concert their bodies with respect to the specimen, as Hanna directs the plate with the slide on top (Table 7.3).

The Professor's first utterance (1) combines a topological/coincidental element ("That turquoise here") with a dynamic, deictic gesture by pointing to a location on the screen that identifies and demarcates an object he wants to further explore. This signals to the novice that she also should attend to this location. Deictic gestures, such as pointing, stand in contrast to iconic gestures like a thumbs up. The spatial location of "that turquoise," the Figure of interest, is topologically determined with reference to a general anatomical structure marked by "here," which functions as the Ground in this interaction. As the old-timer further reason about the nature of this object, he continues to highlight a specific area on the screen by adding three new deictic gestures in rapid succession. By superimposing this dynamic, handmade triangular structure on the screen, Tom materially anchors what first is a fleeting, conceptual object for a second time, thereby making it stable and available as a thing-like thought-object that Hanna can scrutinize on her own (Fig. 7.5).

Table 7.3 Excerpt from conversation

1	**Tom**	That turquoise here, that is the same as we have seen?	*Tom points to an area on the left of the screen ('here'). He then moves his left hand a few centimeters to the right and brings his thumb and index-finger together above a specific location. Tom widens the gap between his thumb and index-finger as he moves it across the screen toward the left, tracing a triangular shape in the area delineated by his index finger and thumb (1–4)*
2	**Tom**	Will the two meet, or?	*Tom's first gesture is followed by pointing gestures identifying three specific locations on the screen, whose lines intersect to constitute a triangle of the same size he drew above (5–7)*
3	**Hanna**	It is strange because they are attached in a way, the two balls, the two sacks, so one would think this was a bit further down, so maybe this is another channel coming?	*Hanna brings her two hands together in an iconic gesture and creates a three-dimensional model of the two 'balls' or 'sacks' she describes seeing on the screen (8)*

Immediately, microscopic visuals seem to constitute an inert and static space, but Hanna and Tom's actions show how this scenery is dynamically and functionally animated by competent practitioners. Static scientific visuals can be activated through grammatical constructions denoting speed, movement, transitivity, and persistence, as well as embodied gesture that superimpose fictive motion on immovable models. Together, these actions produce a kinetic space suffused with spatiodynamic features, which in turn may facilitate novel insight (Alač, 2011; Becvar et al., 2008; Myers, 2015; Ochs et al., 1994, 1996). In his first and second utterance, for instance, Tom's epistemic actions create a conceptual blend composed of an image schema based on a projection of two separate trajectors moving away from each other along paths

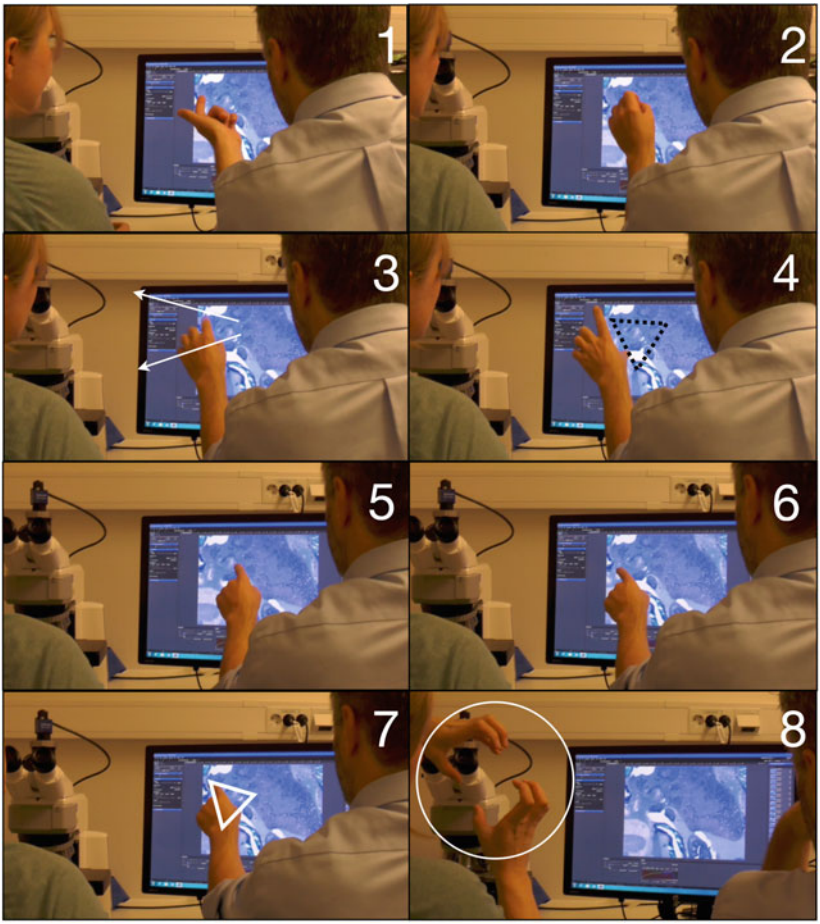

Fig. 7.5 Establishing spatial reference in collaborative microscopy. Tom refers to an observed gland-like complex by first pointing and then superimposing a triangle-like structure on the monitor (1–7). Hanna responds by making an iconic gesture, illustrating a related composite structure shaped like "two sacks" by bringing her hands into proximity and using them to form a model of a round object (8).

originating at the same point. This is an invitation to an imaginary "journey" through tissue, that also encourages Hanna to project the direction of this structure as it extends through other slides in the deck, and more generally throughout the parasite *in vivo*. When Tom makes this thought-object manifest, Hanna can then consider if the two observed structures are likely to "meet" at some future point, by simulating their extension through anatomical space.

Tom's utterances are also invitations for Hanna to participate in the reasoning event. Hanna fulfills Tom's expectation about her involvement by adding layers of meaning about the spatial organization of the anatomical region. He articulates a relevant question along with an iconic "environmentally coupled gesture" that links up things in the world to actions and classifications (Goodwin, 2017). These representational gestures are effective cognitive artifacts, created on the spot during microscopy to sustain situated reasoning about the phenomena in question. Hanna's final co-speech gesture in (3) presents an example of an "iconic mapping" between the gesture's properties, and the structure represented by it (Becvar et al., 2008: 122). Together, Hanna's hands and talk props up a concrete, three-dimensional model of epistemic significance for Tom, who can compare this structure with the two-dimensional visuals he sees on the screen, and then engage in collective reasoning about the features of the relevant anatomical space and surrounding exocrine channels.

Note also that the Professor's deictic highlighting of the triangular structure, and Hanna's iconic gesture of the "two sacks," create conceptual blends that use material structure to move a microscopical phenomenon up to the human scale for further inspection. The fleeting, physical model that Hanna creates by bringing her hands together allows for a comparison through pattern matching with the structure that is available on the monitor. Together, these joint acts of embodied reasoning eventually produce a new insight that there might be another exit channel for glandular products coming up to the same area. Hanna and Tom now had to consider this alternative scenario, as they further explored the properties of the histological scene in detail, adding a new constraint to subsequent interpretations of lice anatomy.

Scientific discourse in this action sequence also seamlessly conflates two different frames, like in descriptions by Ochs and colleagues from a series of illuminating analyses of physicists at work (1994, 1996). For example, Tom's utterance (in 1), grammatically encoded a frame that we can call the "anatomist as experiencer." By uttering "that is the same as we have seen?," Tom establishes the microscopists as two active, reflexive subjects that experience and react to the anatomical entities they have observed. The anatomist is construed as an "active participant," an experiencing agent making scientific discovery (Ochs et al., 1996: 335). However, in the next instance, the professor also verbally and deictically encoded a second, "anatomy-centered" frame. This frame specified certain aspects of the anatomical organization, including changes in its state and spatial distribution.[15] Practicing scientists appear to construe such blended identities to support meaning-making frequently and ubiquitously, in ways that pose no interpretative problem for their peers, despite blurring distinctions between the observing practitioners and their objects of enquiry. It is possible that such indeterminate constructions, whereby scientists retain a certain level of "referential ambiguity" in collaborative interactions, helps to scaffold mundane problem-solving through identification with entities they "struggle" with understanding (Ochs et al., 1996: 348).

Having established spatial consensus about the objects of interest in this anatomical landscape, the newcomer and the old-timer could then proceed to investigate other structures in the near vicinity. But they only did so after having attended to, and blended insights from, three very different referential planes. One plane is provided by the coinvestigators' physical presence and coordination with human-sized objects available in the immediate physical environment. A second, hybrid space of symbolic gestures with deictic and iconic properties, that are superimposed with graphic representations on the screen. And finally, a referential plane that involves imaginative journeys through physical states in the anatomical landscape of lice tissue, such as the alternative paths taken by channels that connect exocrine glands with their openings on the surface of the animal's body. Collaborative microanatomy thus requires establishing precise spatial references that retain sufficient

referential ambiguity and allow co-investigators to productively imagine and deliberate on alternative anatomical spaces.

Tracing Anatomical Reasoning in Notes

Let us turn to a different set of cultural-cognitive practices that contribute to the representational cascade of lice microanatomy, now by examining written notes and graphic displays made by Hanna on basis of repeated sessions in front of the microscope. One of the first external outputs of Hanna and Tom's work, beyond micrographs of exocrine glands and fragments of knowledge embodied by their internal, biological memories, was a trail of entries kept in a hardcover notebook. These handwritten and chronologically organized notes were maintained by Hanna in real-time, as she performed histology. While Hanna collaborated closely with Tom in many microscopy sessions when their project started, she also spent long hours by the instrument on her own.

Similar to the famous notebook kept by the Alzheimer patient Otto in Clark and Chalmer's pioneering essay on *The Extended Mind* (1998), we can usefully conceptualize Hanna's notebook as a type of representational media that supports cognition by extending her biological memory. Merlin Donald, who consider symbolic technologies that represent, store, and transmit knowledge to be revolutionary for the emergence of modern human cognition, coined the term "exograms" to describe such extraneous mnemonic tools, in contrast to the "engrams" of our internal memories bound by the nervous system (2010). Laboratory notebooks, and other forms of paper technology, have long been objects of interest for science studies, since their use provides a window on the weave between information, memory, meaning, and scientific insight (see Holmes et al., 2006: XII; Yeo, 2008). Rheinberger advised careful attention to this "economy of the scribble," as it serves important generative functions in the laboratory as a "trail of rough notes, scripts and scribblings and revised write-ups that offer insight into concrete processes of knowledge formation" (2010: 244).

Scribbles serve many epistemic functions. They are not just tools for information management. In one respect, notes and other kin technologies work as *interfaces* between experimental systems and their conceptual outputs. On its most basic level, writing up microscopy work in external media like notebooks facilitates a process that Rheinberger calls "redimensionalization" (2010: 245). Temporal and spatial dimensions of an investigation can be organized, rearranged, and inscribed on a two-dimensional surface to support a deeper understanding of the epistemic thing in question. Using various representational conventions widespread in the sciences, including discipline-specific tables or diagrams for ordering observations, it becomes possible to synchronically represent sequential events, and render temporal relations in the laboratory into spatial form. Redimensionalization also creates "condensation effects," like the compression and filtering of information over time, through iterations that bring new patterns into view.

Cognitive ethnography and historiographic studies of science share an obsession with minute details of material artifacts involved in the scientific process, such as research notebooks. For Holmes, Renn, and Rheinberger, these media offer a lens on scientific novelty as it emerges in daily interplays between thought, action, and the manufactures of the research lab, potentially challenging our ideas about scientific discovery (2006: xii). To this, the cognitive ethnographer would simply add that valuable insights about this relationship can also emerge from situated examinations of lab work, where notetaking as a generative practice can be studied in real time. By attending to notetaking and its associated representational resources, ethnographically, one can also situate these in a larger sociocultural context where epistemic processes unfold.

Erving Goffman famously made a distinction between the frontstage and backstage of social interaction (1978), which is echoed in the notions of "day science" and "night science", put forth by Nobel-laureate biologist François Jacob (1998: 126). Whereas the former "calls into play arguments that mesh like gears, results that have the force of certainty," the latter "wanders blind": "doubting everything, it is forever trying to find itself, question itself, pull itself back together." Night science stumbles, "a sort of workshop of the possible where what will become the building material of science is worked out," and where "phenomena

are still no more than solitary events with no link between them." We read about day science in reviewed articles and press releases. In these accounts, traces of the inevitable mucking around in the lab that occurs at "night," as new concepts and results take shape in a messy process, have seemingly been scrubbed away (Steinle, 2003). Notebooks like Hanna's, I suggest, offer an interface for attending to transitions between night and day science.[16]

Staff at the SLRC kept meticulous records of their laboratory work in hardback notebooks, and their use reflected widely shared epistemic norms which all newcomers to the lab were expected to abide by. One event illustrates the moral economy of laboratory notes. In a weekly lab-meeting in November 2014, the ethnographer presented some work on information management and the use of databases in biology from a historical and philosophical perspective. When the ensuing discussion turned to the issue of lab notes, the PI remarked that he did not wish to impose restrictions concerning how his research group should organize their logs, and he stressed that staff were free to find their own adequate solutions. He also emphasized the egalitarian ethos of the community, which he contrasted with more hierarchically organized research groups abroad, where notetaking practices were highly regimented. Bioscientific laboratories that are heavily invested in commercially attractive, high-stake research, where competition is fierce and patent disputes frequently arise, are especially prone to require maintenance of notebooks with permanently bound pages, written in pen using conventionalized formatting, and with each page signed and dated. In such contexts, the policing of notes become important because any traces of scientific knowledge production may assume a de facto legal status. While scientists at the Centre were expected to abide by basic epistemic virtues by keeping clearly written, transparent and dated notes, they could maintain these systems of inscription according to personal preference.[17] A notable exception was annotations of RNAi experiments in LiceBase, the Centre's bioinformatic database. As a tool for information management, all were responsible for curating a shared communal directory of data abiding by criteria specified in a checklist.

When viewed as a cognitive artifact, we can identify several epistemic functions in Hanna's notebook. A striking feature was the fact

that Hanna herself was the main recipient for the meanings encoded in the document. Notes were written from her own viewpoint; containing streams of semi-formed sentences and rough descriptions, based on impressions from microscopy events carried out on tissue sections, as these were experienced and recollected by her at the time of writing. While the third-person view was preferred in narrations of her observations, there were occasional interjections of the first-person perspective. In Jacob's words, the notes trace how "writing substitutes a well-ordered train of concepts and experiments for a jumble of untidy efforts, of attempts born of a passion to understand" (1998: 126).

Figure 7.6, a transcript of two typical pages in the notebook, contains the following information from top to bottom. The first sentence indicates what specimen was being examined. Histological specimens made with a variety of staining methods, were frequently exchanged between colleagues at the Centre to support comparative analyses. The second line in Fig. 7.6 introduces a preliminary categorization of exocrine glands ("Type 5"), based on salient traits identified from different staining patterns ("very bright"), and morphological characteristics ("sponge-like"). When supported by other indices, such differences yield the inference that these two structures might be involved in different biological functions. The numbers ("476, 484, 486," etc.) refer to different glass slides in a particular slide box.

In addition to these descriptive listings of salient content from each slide, the notebook is also scribbled with fun facts, jottings of sudden insights, unfinished thoughts, practical tips, reminders, and highlights of specific locations that should be photographed, rudimentary sketches of preliminary structures, groupings, typologies and classifications of glands. It also contains idiosyncratic nicknames for various structures based on salient characteristics. In this case, Hanna refers to "the blue one" (*blåingen*), "the weirdo" (raring), and "the butterfly" (*sommerfuglen*). Together, these scribbles outline a preliminary sketch of a composite model of the exocrine system of *L. salmonis*.

As visible from the figure, Hanna's notebook was organized as a list of observational events, chronologically ordered by section number. This narrative structure facilitated quick and robust information retrieval. A number, usually entered on the left side at the start of a descriptive

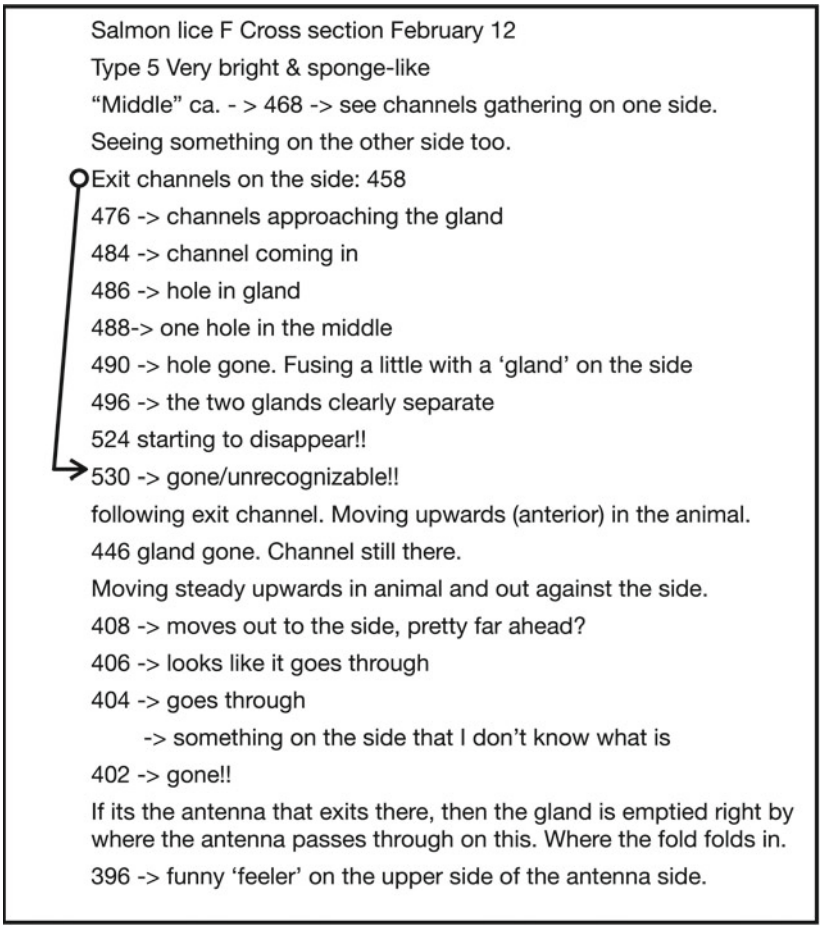

Fig. 7.6 Transcript from two pages in the notebook

sentence, would refer to a corresponding slide in a given slide box. This array efficiently cross-linked the temporal space of observational events with concrete physical locations in the specimen. Note that in the example above, the list of numbers suggest that Hanna has occasionally "jumped" a few slides to speed up her search. The parsimonious inference behind this move is that observed structures remain continuous across consecutive sections: if certain phenomena are visible on both slide

1 and slide 5, they are part of a continuous structure that also appears on slide numbers 2, 3, and 4. A broad search, where Hanna would inspect every slide in each sequence, would likely be too time-consuming to be practically feasible.

The epistemic effects of this bookkeeping effort, such as its mnemonic function, were determined both by its structural qualities and its situated use. First, the device functioned as a cumulative external long-term memory of Hanna and Tom's experiences in front of the microscope. She could, for example, use the entries as what I previously referred to as a "jig" (Kirsh, 1995: 37): a cognitive device that helps to structure and stabilize her informational environment, facilitating easy re-entry to the workflow when resuming work after breaks away from the microscope. Instead of having to inspect each slide in an entire series to relocate interesting landmarks on the individually numbered tissue sections based on internal memory alone, Hanna could instead consult her recent notebook entries. Doing so she could quickly identify critical landmarks and recover regions of interest in the microscope to pursue whatever questions she was addressing.

The notes also served another critical mnemonic function as Hanna was writing up the results in a manuscript for a scientific article. In this context, the rudimentary descriptions in her notes would become one source of data in addition to representations like micrographs, sketches, biochemical evidence from gene expression studies, micrographs from *in situ*-hybridization analyses, and anatomical descriptions found in other scientific publications. Situated in this cognitive ecology, the notebook both served as a record of past accomplishments, but also a springboard for new itineraries and a guide for future action (Fig. 7.7).

This twofold mnemonic character of Hanna's bookkeeping, as both a device for cuing long-term memory *recall* and a storehouse for more direct information *retrieval*, illustrates how epistemic resources are concerted within the larger cognitive ecosystem. According to Richard Yeo, we should see the sophisticated and systematic notetaking practices that developed among English Enlightenment philosophers as important precursors for how contemporary scientists handle their data (2008). English virtuosi like John Locke and Robert Hooke cultivated distinct compilations of knowledge with the help of so-called "commonplace

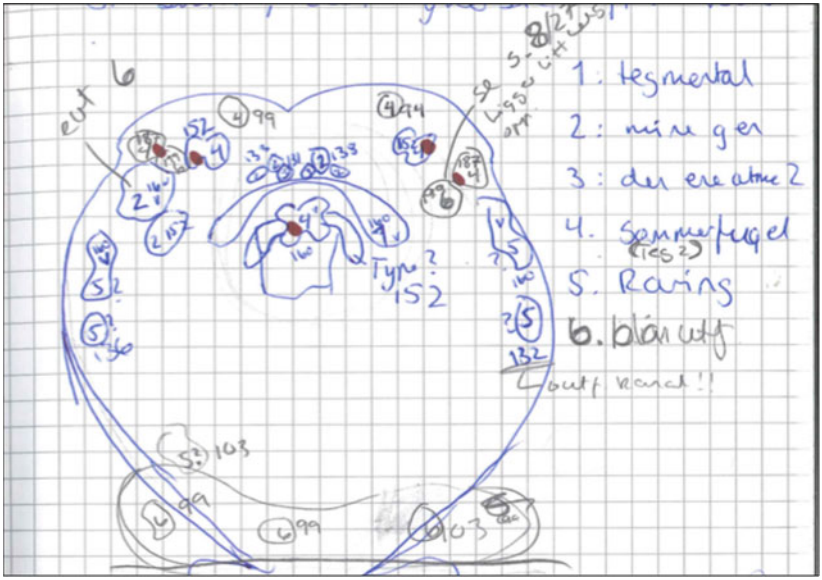

Fig. 7.7 Sketch of a preliminary anatomical map, marking assumed locations of the exocrine system. The numbered legend on the right lists rudimentary working classifications ("1. Tegumental," "2. my genes," "3. the one next to number 2," "4. the butterfly (teg 2?)," "5. Stranger," "6. blue ex[it].")

books." Before the advent of experimental science, natural philosophers conceptualized these individually kept notebooks mainly as memory *prompts* used in the context of memory training, and not as storehouses for knowledge. The purpose of maintaining this species of epistemic artifact was to evoke specific recall events for the individuals maintaining them. According to Yeo, it was not until later that commonplace books were viewed as an external resource for information retrieval. Hanna's notebook constituted a hybrid form of information management that reflected both these epistemic usages. In one way, it was an external record of Hanna's observations. But its fragmented character suggests that the notebook also functioned as a contextual prompt for Hanna's reconstructive and reflexive needs, rather than an external and transparent record where she could retrieve complete information about the anatomical structure of exocrine glands.

The number line, a trajector-based cultural artifact that maps numbers onto a unidirectional space, was frequently used as an organizing device in these exploratory efforts. As a cognitive resource, the number line made it possible to organize entries as *a list that simultaneously encoded both a spatial address* (an anatomical location from a particular tissue section), and *a temporal sequence of observational events* (the situated moment when Hanna made her observation). A "train-of-observation"-style of writing, described the order whereby specific observations were made and how they were interrelated. Each description also referred to numerically arranged tissue slides, neatly organized in plastic boxes. This number line tracked the tissue sections chronologically along the axis from the animal which they had been cut, either top to bottom, or front to back along the sagittal, coronal, or transverse plane.

By organizing her entries as a running list of observations, Hanna also made use of an ancient cognitive device that harkens back to the origin of writing systems. In *The Domestication of the Savage Mind*, a comparative anthropology of the impact of writing technologies on knowledge, Jack Goody asked the intriguing question of "what's in a list?" (1977). This question has deep cognitive implications, although Goody's examples are rather mundane and familiar. Tables with columns and rows are cultural tools whose transmission chain stretches back to inventive scribes in ancient Mesopotamia, working on ledgers in cuneiform script engraved on clay tablets for the public administration. Goody also suggests that lists, as a peculiar form of inscription, have cognitive properties that amplify the mind beyond its "mnemotechnic functions" by encouraging reflection and reclassification of information (ibid.: 109).

Laboratory notebooks are usually ordered as lists of procedural steps adopted from institutionalized biochemical protocols (containing information about temperatures and reagents, for example), as listed sequences of nucleotide or amino acids and lists of research equipment. Sometimes, systems of columns and rows or matrices, are used to order the content. As an example of what Goody dubs "technologies of the intellect" (ibid.: 16), the writing of lists performs quite different operations than what is achieved by ephemeral spoken language, like that uttered during collaborative microscopy. Writing lists of what has been observed and discussed do not only stabilize fleeting perceptual events,

but also domesticates attention, and fixes salient phenomena in a form so that they may later be ordered, classified, and reclassified, on basis of abstract relations. This is why examining the many uses of lists in experimental science, *Listwissenschaft* in Goody's terms, has the potential to open new research agendas and help us better understand how conceptual transitions in science occur (Müller-Wille & Charmantier, 2012). As such, even the humble notebook can be a transformative technology for propagating representational states in the cognitive ecosystem of the laboratory.

Creating Spatial References in the Notebook

When looking closely at how Hanna's notebook accomplishes spatial reference, we see clearly that the entries primarily were tailored to her idiosyncratic requirements for recall, retrieval, and reasoning. While she occasionally created references to anatomical locations using spatial descriptors, such as anatomical place names and constructions of coincidence/topology, her listed observations, as a whole, appears to perform a kind of imaginary, egocentric "gaze tour" in the histological landscape (Levinson, 2003: 33). Hanna's notes achieve this phenomenological effect through a combination of deictic references that point to scientific events of interests *outside* the text (extralinguistic, *exophoric* reference), and by using non-deictic (*anaphoric*) references to earlier descriptions of phenomenon in the preceding text.

Deictic constructions relativize reference to "properties of the speech event" (Levinson, 2003: 69). It locates a Figure *relative* to a Ground (often the "ego"). This is achieved with radial categories like "here" and "there," or with a pointing gesture using hands, eye gaze, or external artifacts. Sometimes called a "viewer-centric" frame, the deictic *origo* (the observer) creates a link between talk and the world. While locative deictic markers in everyday discourse normally evokes the circumstances of a speech-act situation, spatial deixis in Hanna's notebook instead points to an observational context, the moment when her notes were inscribed. As

a result, Hanna's notes appear "semantically deficient," since its "descriptive content" does not identify a clear referent in the absence of other contextual clues (Levinson, 2008: 97).

One reoccurring type of deictic construction used by Hanna to mark spatial reference in these data was exophoric, "gestural" deixis. Ostensive inscriptions of this kind require a form of physical monitoring of the context where the scribble took place to be meaningful (usually in the form of visual information). In the following excerpts, sampled from the image reproduced above, a semantically sufficient interpretation requires access to a range of contextual information, and even graphical representations outside the text:

> *Looking at brighter/larger vesicles in the midline. Laying in plane with the butterfly. Ex. channel exits 154.*
> *NB > not the one that is lying outside.*
> *Following it down in the animal.*
> *169 > see channel cut lengthwise. Moving up in the animal.*
> *168 > moving upwards again!!*
> *Waving its way to the top 166.*
> *Following this all the way out.* (170)

These contextually dependent spatial references were often framed in terms of directional contrasts, and relied extensively on demonstratives ("these," "those," "here," "there," etc.)[18]:

> *774 > channel goes out of the glandular tissue.*
> *Jump back to 780.*
> *764 > channel no 2 moves sideways.*
> *764 > it moves out!*
> *748 > none of the glands were there. It is seen near good* [sic] *748.*
> ….
> *722 > starts to show up in middle.*
> *706 > butterfly is here.*

Both excerpts from Hanna's dataset depend on supporting information of a contextual kind to be adequately meaningful for the user. To complete the meaning of these inscriptions, the reader must have

access to a range of media, such as other pencil sketches, particular micrographs, and knowledge about the material qualities of specific slides, as well as intimate familiarity with observational events from the course of microscopic work. Occasionally, these notes also illustrate how Hanna conducted "interpretative journeys" (Ochs et al., 1994), in the anatomical landscape on her own:

S06 > it moves alongside, outwards to the right (if I was the louse).

In this inscription Hanna, as the observer, creates a blend for spatial reference that takes directional aspects from the anatomically conceptualized body plan of *L. salmonis* as one input, while the other input is materially anchored through her own phenomenal experience of a *situated* body-as-louse. Given that Hanna had carefully examined each of the tissues described in the notes with her hands and eyes before, she could recall these observational events and simulations by using the scribble as a cue.

The notebook was also littered with deictic references. Fillmore described the contrast between deictic and non-deictic spatial reference as analogous to the difference between a three-dimensional sculpture of a human figure in the middle of a courtyard, and a photograph of this figure (1997: 28). While the former is not fixed and can be inspected from any vantage point, the photograph is always taken from a fixed place and perspective relative to the figure's position. For example, we can see from the transcript (Fig. 7.8, line 2 and 3, page 2), that Hanna made the following note:

404 > goes through.
> something on the side that I don't know what is.
402 > gone!!
If it's the antenna that exits there, then the gland is emptied right by where the antenna passes through on this. Where the fold folds in.

These examples of textual-discursive and gestural deixis ("exits there," "passes through on this"), require both the textual availability of preceding information, in addition to other sources of memory about the observational event to constitute meaningful spatial reference. In turn,

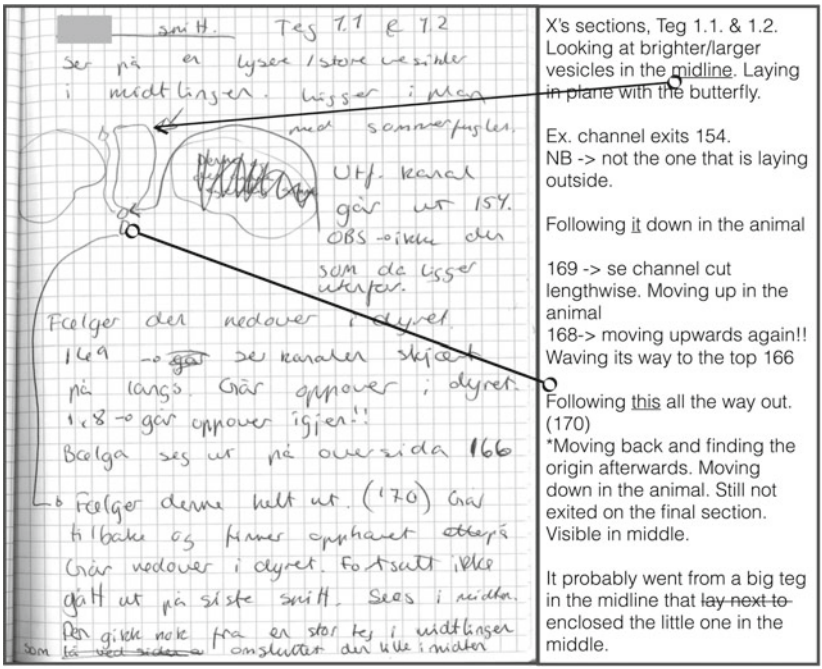

Fig. 7.8 Sample from a notebook entry with a transcript (on the right). Disambiguating a complex anatomical structure, the sketch contains examples of "gestural" deixis in the form of an annotated sketch that highlight relevant locations, and "discursive" deixis referring to observational events that precede the moment of writing. Hanna's use of gestural deixis requires a visual inspection of the hand-drawn arrows for meaning completion (here, annotations highlight the words that the original arrows in her transcript refers to)

this informational gap can only be bridged by Hanna who conducted the histological investigation, as she is capable of coupling internal, representations "in the head" with external representations inscribed on paper and other media in the material world. She can thereby exploit whatever Gibsonian "affordances" are available on the spot, through acts of embodied, pragmatic meaning-making (Levinson, 2008: 106).

To appreciate why Hanna's notes were structured in this particular manner, one must look at the context of their production. They were written down while she was orienting toward the microscope, sometimes during engagements with her mentor Tom, or other colleagues. Chains

of interactions with the microscope assembly were translated into trains of thoughts, recorded onto paper. Her representations in the notebook transformed anatomical phenomena mediated by the microscope into tangible symbolic inscriptions. Commenting on an early draft of this manuscript, Hanna added that she also operationalized a word document on her PC as an additional reflexive medium to engage with the material. After a session in front of the microscope, she would return to her office, notebook in hand, to trace out her observation directly in a draft scientific manuscript through repeated iterations.

Another function of lab notebooks, as data management tools, is to ensure a transparent and redundant record of information, in case a member leaves the research community, for example. One could imagine a hypothetical situation where Hanna's colleagues used the notebook entries to partially reconstruct her anatomical work on exocrine glands. For example, by combining the notes with graphic descriptions like micrographs and diagrams from other sources. But due to the notes' semantic deficiency this would be challenging. Hanna's entries required the author's contextual know-how to be composed into a meaningful whole. For this reason, the notebook cannot be considered as simply a data recording device. Her entries are not "immutable mobiles" that travel easily across time and place (Latour, 1990: 26). Instead, the notebook's epistemic status can best be understood as a "data generator" (Hacking, 1992: 48), whose cognitive role was to facilitate the transformation of one type of representation into a different format. Its full epistemic potential could only be attained when these generative scribbles were coupled with Hanna's embodied know-how, alongside other media such as graphical outputs from the microscope-mounted camera, to build accessible accounts of microscopic observations. It was in these productive couplings that the scribble's true power resided.

Spatial Reference in the Manuscript

I have described Hanna and Tom's eclectic use of cognitive resources, including angular and non-angular constructions, for establishing spatial reference and joint reasoning about microscopic exocrine glands. Their

shop talk in these interactions was littered with construal operations like topology, place names, and varieties of deixis ("point-out-ables"). We also saw how spatial reference was idiosyncratically encoded in Hanna's notebook. But strikingly, spatial representations, both in their natural discourse and the notebook, revealed surprisingly few traces of anatomical terminology. One might assume, *a priori*, that this specialist vocabulary would be essential for conducting microscopy. For example, a simple content analysis of the 81 pages in Hanna's notebook revealed only nine instances of explicitly anatomical terms of location to render spatial descriptions: four instances of *dorsal*, three of *ventral*, and two of *anterior*. Now, compare the spatial descriptions we have encountered in excerpts of natural discourse and Hanna's notebook with the following examples of spatial reference. These are sampled from a draft manuscript for a peer-reviewed scientific article that was the primary output from Hanna and Tom's investigation: "The most anterolateral pair of teg 2 glands have a duct extending anteriorly and out together with a teg 1 gland where the anterior margin of the cephalothorax contacts the antennules. The next cephalic pair secretes their content dorsally. The teg 2 glands in the thoracic leg 1 and 2 sympods have ducts leading adjacent to the joint between the sympod and exopod/endopod, while the teg 2 glands in the exopod/endopod have ducts protruding into the distal segment. The pores are found anterior on the exopod distal segments (Fig. 3F), while on the thoracic leg 2 endopod they are located at the marginal margin between two of the distal segment pinnate seta."

Here, each sentence in the paragraph provides a detailed description crafted through the use of anatomical terms of location. Each descriptor is also cross-referenced with annotated collages of micrographs assembled from both light microscopy and scanning electron microscopy. Together, these representations offer a dense model of the parasite's exocrine system, saturated with anatomical meaning for expert readers. This constitutes a remarkable transformation in the representational format used to describe the spatial characteristics of exocrine glands. Everyday language, as it appeared across many interactions in the wild, has been substituted with careful anatomical descriptions of the parasite, using terms of location derived from Latin and ancient Greek. The translation follows established standards in the biological community

for disambiguating meaning and communicating about the location of biological entities. Reducing referential ambiguity in anatomical descriptions is critically important when dealing with epistemically vigilant peers, whose job is to evaluate the reports of other research colleagues. A reader cannot usually access the same contextually embedded resources that were available to the authors who performed the inquiry. Instead, readers rely on technical descriptions and annotated, two-dimensional figures. According to Hanna, a key resource for developing the right vocabulary and accomplish this transformation, was a "fantastic" paper describing the major body parts of the salmon louse.

Another excerpt exemplifies this representational "upgrade" through an elaborate locative description of a specific type of gland. Hanna and colleagues eventually categorized this as "teg 3": "The teg 3 glands are found evenly distributed laterally along each side of the cephalothorax within the subcuticular tissue (Fig. 4B), with five glands on each side. Their ducts run posterolateral, extending through the cuticle ventrally on the marginal membrane in the vicinity of an innervated bifurcating sensilla seen at the margin (Fig. 4C, D). The sensilla nerve follows the course of the teg 3 duct, but synaptic contact between the nerve and the gland could not be confirmed with light microscopy. Teg 3 glands are also seen within the distal segment of the endopod/exopod of the thoracic leg 2, and posterior within the sympod of thoracic leg 3 near the interpodal bar and more laterally near the base of the thoracic leg 3 exopod with a cuticular pore at the margin (Fig. 4B). Pegs with pores (Fig. 4G) are seen nearby the teg 3 pores at the posterior margin of the thoracic leg 3 sympod (Fig. 4B, F)."

In addition to the non-angular terms of location encountered earlier, descriptions in these two excerpts rely on what Levinson describe as an "intrinsic frame of reference" (2003: 41). This is an object-centered coordinate system based on anatomical planes. In this system, coordinates are based on features, sidedness, or facets of objects that function as Ground (the relatum). Levinson points out that these features are not inherent in the objects, as is sometimes assumed, but get assigned by language-users on case-by-case basis. Anatomical terms of location can be conceptualized as a box-like, six-sided framework superimposed on objects in the standard anatomical position. As with other intrinsic

systems in English and Norwegian, it is oriented by gravity. The bottom becomes the undermost facet, and the animal's top is the uppermost facet. Front and back are decided by establishing the direction of the organism's perceptual apparatus, like its usual direction of motion. Bilateral, symmetrical animals like *L. salmonis* are also attributed with sides. This yields a total of six polar opposite facets. Three pairs of polar opposites yield three axes intersecting at right angles, together constituting a three-dimensional geometry (Fig. 7.9).

In Norwegian and English, language users normally employ functional criteria to assign the features, sides, or facets of objects in the

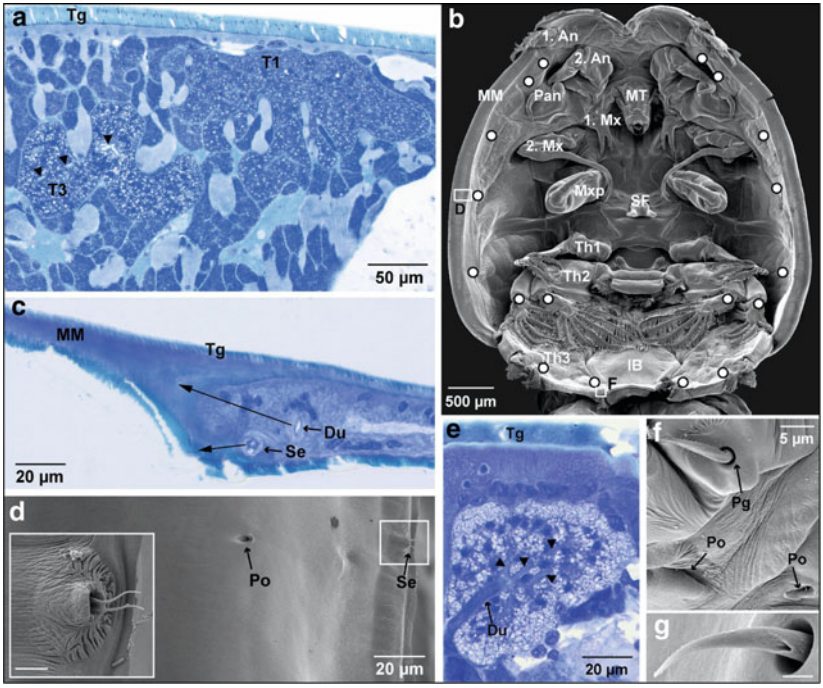

Fig. 7.9 An annotated montage of micrographs from SEM (b, d, f and g) and light microscopy (a, c, and e), supporting the locative description (Øvergård et al., 2016). Figure and accompanying text contain inscriptions that assist in the interpretation of data, such as a scalebar and information about lens magnifications (Reproduced with permission from Wiley & Sons)

intrinsic frame, while other languages can solve this problem differently. Conceptual properties of objects like shape, canonical orientation, characteristic motion, and use are all attributes that may be employed for this rendering. In the intrinsic system then, the Ground (relatum) and the Origin of the coordinate system constitutes the same object, creating a spatial binary between Figure and Ground (as opposed to the ternary relations used for the relative reference frame, see Levinson, 2003: 43). Having established the "front" (anterior) of a biological object, the cognizer can anchor "a ready-made system of oppositions" such as "back" (posterior) and "side" (lateral) along the organism's intrinsic axes (ibid.: 41). This is done by extracting an angle or line radiating out from the Ground object's centroid mass or facet. The main object of interest (the Figure) will then be located within or on this angle/line at a determined, specified distance. So, having identified the "anterolateral pair of teg 2 glands," the glands positioned in front and to the side in the above quotation, a proficient biologist can then identify a duct that extends frontally together with the teg 1-gland. The position of the teg 1-gland gets defined by an arc from the frontal facet of the cephalothorax, a body part which is adjacent to the antennules.

In contrast to the natural discourse and the notebook descriptions surveyed above, no circumstantial information about their context of production is necessary for these descriptions to be meaningful for specialists. With special purpose anatomical terms of description, named facets of objects provide anchors, instead of anchors being defined based on the direction of gaze or gesture by an observer, as in the relative frame of reference.[19] In the intrinsic frame, rotation of the viewer and the entire array will yield equivocal descriptions, while a rotation of the Ground object will not. In the relative frame the opposite would be the case: rotation of the viewer and the whole array would yield different descriptions, and rotation of the ground object will yield the same description. Being allocentric, the intrinsic system thus yields an "'ego-invariant' picture of the world out there" (Levinson, 2003: 54), highly suitable to convey precise renderings of a complex, microanatomical domain to others. Here, we see that spatial reference to the phenomenal objects of interest has transformed into a specific, external coordinate system. This intrinsic frame uses the facets of anatomical objects as a Ground to

establish the position of the salient Figure to be described by mapping each one along the object's intrinsic axis. Through such representational means, "any whiff of the personal, any human odor" is removed from a research process that is inherently situated and embodied (Jacob, 1998: 117).

To appreciate the absence of anatomical terms of location during microanatomy and in the notebook, it is necessary to keep in mind that Hanna started out as a novice in microscopy. As she progressed through her project, one of the major changes in her practice was a transition from using everyday folk language for marking spatial reference to become a competent practitioner. This included the ability to recast and articulate her observations of lice exocrine biology in specialized anatomical terminology. Throughout this process, the novice learned how 'to see' phenomena like exocrine glands, exit channels, and other structures with the microscope. This cognitive accomplishment required her to move between complex representations, integrating information from different domains in ways that represented and re-represented the problem-space many times over. Hanna articulated how the translation of her notebook description into the professional discourse of microanatomy, the precision tools of the trade, involved a major learning transition from her background as a molecular biologist, primarily working on gene expression. Commenting on this section, Hanna also believed that a trained histologist would have used more anatomical terminology in their scribbles, and she suspected that Tom did not want to overburden her with too many technicalities when they set out on their anatomical quest.

The manuscript's fate reveals another dimension to Hanna's challenges with becoming a professional, as she also had to navigate between the expectations and epistemic interests of morphologists and molecular biologists. Differences in scope and interest proved difficult to reconcile at first, as the researchers submitted their work to a specialist journal on arthropod anatomy. One reviewer was quite positive about the manuscript and the figures, with the exception of some minor disagreements about dyes and staining methods. Unfortunately, the other reviewer was harder to satisfy. Finding the paper's claim inadequately substantiated, the review argued that that the paper contained no detailed morphology of gland *structure*. According to the reviewer's

understanding, this necessitated a more extensive use of transmission electron microscopy. This critic also identified a mismatch between the scope laid out by the paper's title, and the types of data that was presented to fulfill the stated ambition. There was also disagreement about interpretations of empirical data concerning some of the proposed glands. While Hanna rectified the title, and addressed all of the peer comments, including what she considered to be serious misunderstandings by the most critical reviewer, the journal's editor ultimately rejected the paper. Here, the main point of contention was that the figures, in agreement with the latter reviewer's objection, contained "no high-quality morphology." In Hanna's opinion, the Centre's emphasis on a functional genomic approach to exocrine glands for understanding host–parasite interaction did not resonate well with the journal's *structural* emphasis. After this rejection, Hanna resubmitted the article to a journal with a broader appeal, that could perhaps better appreciate both its scientific and applied relevance. While the second round of peer-reviewers also commented on lacking data from transmission electron microscopy, and requested alterations to figures and more detailed annotations, the paper was eventually accepted and published.

In crustaceans, exocrine glands serve many roles depending on the organism's lifestyle requirements. By the end of their investigation of the exocrine system, the team converged on a classification of four types. The first three were labeled "Teg 1," "Teg 2," and "Teg 3," because they were functionally associated with the outer body ("tegument"), while the fourth group were named "Labial" because these glands were located in the *labium*, the lower part of the parasite's mouth tube. As categories, these functional groupings of glands can themselves be understood as conceptual blends, containing input spaces from a wide range of domains like morphological information about form, texture, and color, functional aspects, developmental timing, anatomical position, and sites of secretion, that together constitute new groupings of biological structure. Hanna and Tom conjectured that Teg 1, the most numerous glands in adult salmon lice, excreted substances that maintained the tegument, while Teg 2 most likely produced substances protecting high-friction areas around the organism's body. Teg 3 was predicted to have several functions, since its development coincided with the virulent, pre-adult

stage of the lifecycle, the time when lice attach and start inflicting serious damage on the host. Along with the Labial-gland, Teg 3 was suspected to secrete factors that modulate the salmon host immune system. While tegmental glands consisted of only one secretory cell, the labial glands were composed of two larger secretory cells with individual reservoirs emptying into a joint duct that released its content when the parasite fed off the host.

Multiple methods helped to meaningfully home in on these groupings. Morphological data was supported by identification of marker genes detected through fluorescently labeled RNA-probes that visualize locations of gene expression of target sequences in tissue. Applying *in situ hybridization* to the Teg 1 glands revealed two *astacin*-coding genes. These genes belong to a family of enzymes known as *metallopeptidases*, which are used by parasites to modulate their host. *In situ* also revealed a *fibronectin type II*-domain gene that possibly served antimicrobial functions. The Teg 2 glands expressed a *heme peroxidase* gene, which was of interest because of an earlier inconclusive study on lice glands that detected activity of this enzyme in the parasite's oral cone (a finding reproduced by Hanna and Tom). At one point during the investigation, these enzymes were hypothesized to protect against the salmonid immune cells by limiting the narrowing of blood vessels and reducing general inflammatory responses. Additionally, the *in situ* method yielded fine-grained structural information about Teg 1 glands, which were shown to have three subtypes based on differential expression patterns. Awareness of these be valuable in future experimental work.

Structuring Microscopic Experience

How does a small group of biologists move from stray observations of microscopic objects on a thin section of biological materials embedded on a glass slide, to plausible descriptive models of a biological system on the human scale? They do so by reasoning with different representational artifacts and scientific visuals through a variety of ecological assemblies. Tissue slides are tangible entities: tiny pieces of biological matter sampled from salmon lice that contain the phenomena of

interest. These phenomena also appear as second-order graphic representations projected on the computer screen, and as third-order graphic representations embodied by environmentally coupled gestures and embodied notebook scribbles which animate and tie language to specific phenomena situated in a cognitive ecology.

By fashioning many different forms of attainable structure through their heterogeneous interactions, the investigators could, over time, coordinate and navigate their way through the salmon louse. Traveling through different parts of the organism, section after section, Hanna and Tom used a range of different construal operations to jointly structure their visual experience and create spatial reference. Instantiating what Alač calls "malleable fields of interaction," the media I have surveyed here affords scientists with many different opportunities to explore their investigatory materials (2011). Although camera-generated images of microscopic phenomena, for example, may seem to be salient because they embody 'objective' properties of the world, their epistemic powers really derive from such malleability. Like many other kinds of scientific visuals, micrographs have a double identity. They are epistemically productive precisely because they are both indexical and iconic signs. Their indexicality stems from the causal relations between the tissue structure, and how it appears when seen with the microscope. But micrographs also have iconic properties; they not only share similarities in an image-like manner with the target object of the investigation (gland structures *in vivo*), but also require embodied enactments through skillful acts of perception that function as "infrastructures for seeing" (Alač, 2011: 24).

Hanna and Tom's observations of exocrine gland anatomy, across fields of interaction, were deeply structured by a collection of basic image schemas, the embodied and generative cognitive structures for meaning construction, described in the previous chapter. In particular, both an embodied logic of CONTAINMENT, as well as a SOURCE-PATH-GOAL-schema, were central for supporting reasoning about lice glands both in first-order, second-order, and third-order representations. The CONTAINMENT-schema, for example, has a physical basis in human phenomenology and consists of an inside, an outside, and a separation between these two domains by a boundary, with the inside seen as a

bounded region in space (Johnson, 2008: 138). Our bodies have boundaries, and so do the vessels we encounter in our environments, exocrine glands included. Containers, like glands, can be filled, or emptied. The CONTAINMENT-schema also has transitive properties. If an entity X is inside of Y, then placing Y inside of Z also transfers X. Exocrine glands are conceptualized as locations contained in three-dimensional space within the organism, which can be further partitioned into specific tissue regions. With respect to the substances produced in these locations, glands are conceptualized as containers for biochemical substances within the larger container of the louse body (Fig. 7.10).

A shared logic of CONTAINMENT allowed Hanna and Tom to perform a variety of conceptual transformations during their observations across representational substrates, such as reasoning about entries, enclosures, partial closure, and force-dynamic transformations. As seen with the microscope, individual tissue sections do not afford a direct view of the salmon louse as a three-dimensional structure. Instead, a fictive three-dimensional model had to be created by imaginary, and physical movements, through consecutive sections of tissue. As mentioned, Hanna would occasionally make observational jumps from one slide (number 346, for instance) to another section (say, 357) in a given specimen, depending on the necessary level of resolution that was required to identify the biological structure. On basis of these sampled observations from a larger biological segment, a composite model could then be scaffolded from a wide variety of mnemonic resources.

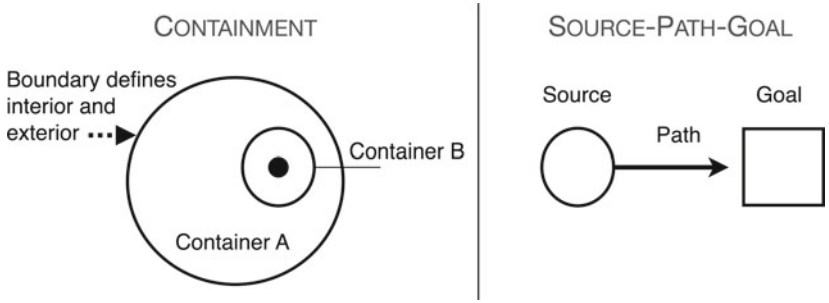

Fig. 7.10 Basic schematic structure of containment and source-path-goal

Exocrine gland anatomy was also supported by another key conceptual structure, namely the SOURCE-PATH-GOAL schema of directed motion (Johnson, 2008: 142). This schema guided Hanna and Tom's conceptual movement "through" the louse specimen, as they followed channels that ran from individual glands to surface exit points. The schema was also activated when substances were described as moving in and out of cells and the glands' exit channels. Such operations involved a superimposition of the SOURCE-PATH-GOAL schema onto the CONTAINMENT schema. Like CONTAINMENT, SOURCE-PATH-GOAL was invoked for event structures where an object moved from one location to another. It included a trajector (a moving object), a source from which movement originated, and a target goal. Reasoning about these properties also entailed questions of locality (i.e., a trajector's current location along a path), and directional forces moving away from the source toward the target. These movement schemas, which may include passage of time, stem from embodied experiences with movement of self, other agents, and objects.

SOURCE-PATH-GOAL was indispensable for Hanna and Tom's generations of rich meaning during gland anatomy. For example, what the two called *secretory tubules* originated in a *syncytium* that together constituted a *gland*. Glandular contents were collected in *ducts*, which moved via body parts like the *cephalothorax*, and exited on the parasite's *cuticle*. According to this logic, ducts could be traced in order to see whether they exited on the top or bottom of the parasite. The schema thereby scaffolded inferences about the structural–functional relations between the glands, such as whether the glandular content was for maintaining the tegument (top exit), or for modifying the host's immune system (bottom exit). But due to its salience, this schema could also support spurious inferences. In one case, illustrative for the power of schemas to structure experience, my informants painstakingly followed a sequence of objects leading out from a particular gland for hours, across many tissue slides. Initially, these objects were assumed to be an exit channel for glands. Only after intense checks and re-checks, did Hanna realize that the structure they had been tracking was not an exit channel at all. Probably, it was a neuron that ran alongside, and eventually branched off from, another structure they correctly figured was an exit channel.

Cognitive anthropologists assume that metaphoric expressions, as manifested through language and other communicative modalities, are tokens of more widely shared, instituted cultural models (Shore, 1995: 53). Such models are not just privately entertained by individuals, as internal mental representations, but may be publicly distributed in various forms, including those stemming from joint action and practice. The dynamic between publicly instituted and private mental models, what Shore aptly calls "the twice-born character of cultural forms," gives rise to a diverse dynamic of cultural transmission (ibid.: 68). The conceptual metaphor of GLANDS ARE CONTAINERS, for example, creates a shared cognitive artifact whose twice-born nature mediates the mapping of exocrine structures in salmon lice. It is both internalized by each practitioner, but also shared through public representations and intelligent actions within a scientific community.

Toward a Cognitive Ethnography of Microscopic Vision

In this chapter, I have stressed the importance of linguistic modalities for how cognition gets distributed during microscopy. But I do not suggest that knowledge is always encoded in language, or that language is a privileged channel for knowledge. Such a view would conflict with the cognitive framework chosen here. Instead, the emphasis on language has been empirically motivated since it emerged as an epistemically valuable resource for my interlocutors during microscopy. As science is "a world of ideas in motion" (Jacob, 1998: 117), language and writing are technologies to domesticate fleeting impressions in the laboratory.

I have shown how joint spatial attention to scientific phenomena during socially situated microscopy is achieved by a range of semiotic means. One way that vision was domesticated in these interactions was through verbal triangulations between several adjacent landmarks in anatomical space. In part, Hanna and Tom navigated their landscape by peering into the microscope's ocular and consecutively highlighting salient structures by verbalizing topology, deictic descriptions,

and anatomical placenames. Through these linguistic means, each participant encouraged the other to shift their attention among entities by alternating between Figure–Ground relationships. Andy Clark captures how language confers epistemic powers through such mundane referential operations: "To formulate a thought in words (or on paper) is to create an object available to ourselves and to others, and, as an object, it is the kind of thing we can have thoughts about. In creating the object, we need have no prior thoughts about thoughts – but once it is there, the opportunity immediately exists to attend to it as an object in its own right. The process of linguistic formulation thus creates the stable attendable structure to which subsequent thinkings can attach" (2006: 372).

With these vehicles for practical thinking, Hanna and Tom could engage in scientific explorations, like the "interpretative journeys" identified by Ochs and colleagues in ethnographic studies of physicists at work. These are "sojourns that may take place both in the world of physical events (through taking on the identities of physical objects, or by animating and anthropomorphizing them), and the world of constructed visual representations as a cognitive and spatial domain to inhabit and wander in" (Ochs et al., 1996: 350). Sometimes these journeys happened without alteration of the physical media that was being traversed. On other occasions, transformations of media were crucial for the making of novel conceptual blends that could spur new insights about exocrine biology in salmon lice.

The ecological assemblies facilitating such microanatomical journeys required opportunistic use of a range of semiotic modalities besides language. In the first ethnographic vignette (Fig. 7.1), the pair examined biological structure in a microscope equipped with two individual eyepieces. In this session, both collaborators could monitor the specimen while Hanna directly manipulated the tissue slide. Here, there was a limited range of communicative modalities available to the two collaborators; since the material affordances of the assembly required both to peek into the ocular to see the objects of interest, resources like pointing hands and directive eye gaze were not immediately available for inspection. The communicative act of pointing and creating spatial reference

to locate a shared referent had to be solved differently. We saw how physically moving the specimen and changing the object's focus to highlight phenomena of interest, gave Hanna alternative, nonlinguistic means to create shared spatial reference. The microscope was also equipped with a deictic pointer, a small arrow superimposed on the visual field, which a skillful user could use to support a visual search and construe shared reference and meaning. In other contexts, these epistemic actions were conveniently served by other semiotic modalities.

We saw an example of these modalities in action when the two histologists worked on a microscope equipped with digital camera mounts that projected images to a computer monitor. This setup afforded the use of alternative representational media for meaning construction, with the screen providing an additional field of interaction for joint attention. It made accessible resources for shared spatial reference through deictic marking, using the mouse pointer, various pointing gestures, and forms of touch. The screen also afforded the invocation of iconic signs. These could be used to annotate the existing anatomical landscape by providing a material anchor for conceptual blends that could be richly elaborated by both Hanna and the Professor through interaction. Iconic gesture also facilitated visual comparisons between gestural models and the structure available on the screen, adding concreteness to abstract models of exocrine biology. While not shown in the above transcripts, I observed multiple instances where the objects of interest in the microscope, as seen through the ocular and on the computer screen, were compared and juxtaposed with various other external representations and models on paper, such as printed anatomical diagrams from scientific articles and other sources. These ecological assemblies created additional stability between different visual representations and were central for "seeing" glands as a scientifically salient phenomenon.

My ethnographic observations of these microscopical journeys resonate with Gooding's proposal that visual inference in scientific practice basically consists of a series of generative transformations (2004). In his analysis of how paleo-biologists reconstruct extinct organisms, Gooding shows how "word-image-object hybrids" become epistemically powerful by integrating different forms of multimodal knowledge and experience. This, in turn, supports a continuous movement between the

personal domain of internal, mental representations to public tokens of meaning and the conventions that govern these (ibid.: 581). Transformations carried out on plastic representational media can either reduce or increase this informational complexity, with far-reaching epistemic consequences. The act of extracting features, relations, and patterns in the many figures and diagrams fashioned by Hanna and Tom, occasionally simplified complex representations like tissue slides by *reducing* their informational content. Such reductions could serve to highlight exocrine gland structure, along with meaningful, explanatory accounts of their organization. But the scientists also made enhancements to integrate information from different sources in ways that *increased* representational content, by juxtaposing and aligning representations that were inadequate alone, but together captured invariant features of a microscopic world. As we saw, any derived model of salmon lice exocrine morphology had to satisfy constraints from several domains, not just microanatomy. Such technologies of the mind worked through a complex interplay of internal (private) and external (public) representations.

This ethnographic investigation has described how complex low-level cognitive processes such as stereoscopic visual perception becomes culturally orchestrated through language, acting bodies, and a suite of material artifacts. Together, these provide tools for thinking about biological systems at the microscopic level. Here, I have used cognitive ethnography and the framework of distributed cognition to reconstruct some of these practices. The video camera, coupled with participant observation and scrutiny of artifacts, and inscriptions that are produced and consumed by the community in question, show the value of attending to night science. Night science is not epistemically dubious. However, scientists may sometimes express discomfort when talking about these aspects of their research. Not only does night science detract from idealized, normative models of scientific work, but there is also a perceived trade-off between making and publishing new discoveries and investing in deep reflexive engagement about its many facets.[20]

We have seen why microscopes do not facilitate perceptual augmentation for seeing the microscopic in the same way as eyeglasses help people with poor eyesight to see better. Microscopic vision is not passive, but an

interactive process of meaning-making that requires skillful integration of many types of supportive media. These cognitive practices, in turn, facilitates modeling of an otherwise invisible world.

Notes

1. These conversations were done in Norwegian. All translations by the author.
2. Commenting on a draft, Hanna explained that the structure in question probably was a muscle tendon attachment. When cut straight across, the structure could be mistaken for a gland.
3. Someone had also replaced expensive objectives from one of the labs with lower-quality microscope objectives. This event raised questions how access to the facilities should be regulated.
4. Retraction Watch monitors these events. See: www.retractionwatch.com.
5. Although similar in many respects, electron microscopy uses other reagents, and sections are cut thinner.
6. Different microscopes use different techniques, e.g., microtomes with diamond knives for transmission electron microscopy, and cryo-sectioning with cryostat-devices for oncological applications.
7. Scanning electron microscopy was first used in 1942, 11 years after transmission electron microscopy appeared. TEM relies on a transmitted electron beam passing through the sample to form an 'internal' image of the specimen beyond the surface. It is used for thin sections, to visualize an extremely small scale (around 0.5 Angstrom). Electron microscopists used six epistemic principles to decide what biological experiments show: validation of theory by instrument, calibration with precedented knowledge, calibration with independent methods, practicality, aesthetics, and the inference to function (Rasmussen, 1993).
8. This is the 'grid-argument' about the reality of unobservable entities. Make a machine that carve consecutively smaller grids on a surface, some being invisible to the naked eye. Look at the surface through a microscope and see the same grid-structure as those visible without augmentation. It would be unlikely that this is a coincidence. Hence, we can be confident that microscopic entities exist. A skeptical response is that we cannot assume what is in dispute; namely whether we actually made the grid to be that way.

9. The term 'Sitting-with-Nellie' is used to describe situations where a trainee learns a job poorly by observing an experienced person, often haphazardly without a plan. The trainee might learn much, but can also pick up bad habits, since the senior does not always have the skills necessary to train others well. My use here does not imply any value judgements.
10. Mody and Kaiser points to similarities between this pedagogic style, often based on legitimate peripheral participation where newcomers gain experience through low-risk tasks, and participant observation (2008).
11. In some clinical contexts, other planes of reference, such as the parasagittal plane, are used to carve an organism into unequal halves, as well as composite planes for distinct regions or body-parts.
12. Distal (away from) versus proximal (close to) are polar opposites, used independently of axial planes.
13. Deixis and 'indexicality' are overlapping terms used in different traditions of linguistics and philosophy. The latter describe contextual dependency in meaning, while the former is used in a narrow linguistic sense.
14. Person-deixis refer to speaker-identity, place-deixis refers to individual location, and time-deixis refers to (a) when a message is sent, and (b) decoding time. Interpersonal relations manifested in honorifics, politeness, and intimacy-talk may constitute social deixis, and audiences of deictic reference do not always participate in the speech act, as deictic elements can display two layers of conceptualization: one relative to participants' situatedness in the speech act, and a construal displacing the situation to a different time and place, i.e. 'deictic projections' that displace the deictic center to an imaginary agent (Croft & Cruse, 2004: 60).
15. Ochs et al. show how scientists frame and enact objects of inquiry as sentient agents (1996: 338).
16. This distinction mirrors that between the context of discovery and justification. Logical empiricists claimed that the purpose of philosophy was to describe the logical structure of scientific theories, and relations between theory and evidence. A consequence was the exclusion of scientific discovery and practice from the scope of philosophical investigations, and a lack of interactions between epistemology and the empirical enterprise of science studies, broadly construed. This separation has been challenged by "Friends of Discovery" in the philosophy of biology, for instance (Schickore & Steinle, 2006: vii–viii).
17. Under the slogan 'no insider information', the Open Notebook Science-movement works to set free 'dark' data (failed experiments included), by transparently sharing notebooks without limitations.

18. In Norwegian, Hanna's working language, demonstratives are determined by the gender, number and distance in relation to the deictic centre that determines its form (dette, den, det, disse, de, her, der). Some languages use demonstrative systems that indicate different distances from the speaker, listener or both, while others use more complex systems.
19. Levinson claims that for informational content in spatial descriptions there are only two semantically acceptable translations between Frames of Reference (2003: 59). One can move from an orientation-bound, relative frame to the orientation-free, intrinsic frame, or from the absolute to the intrinsic.
20. Peter Medawar provocatively asked if this means that scientific papers should be considered fraudulent (1996). On the perils of sanitizing research in science education, see Howitt and Wilson (2014).

References

Alač, M. (2011). *Handling digital brains: A laboratory study of multimodal semiotic interaction in the age of computers*. MIT Press.

Alač, M., & Hutchins, E. (2004). I see what you are saying: Action as cognition in fMRI brain mapping practice. *Journal of Cognition and Culture, 4*(3–4), 629–661. https://doi.org/10.1163/1568537042484977.

Barth, F. (2002). An anthropology of knowledge. *Current Anthropology, 43*(1), 1–18. https://doi.org/10.1086/324131.

Bateson, G. (1972). *Steps toward an ecology of mind.* Chandler Publishing Company.

Bechtel, W. (2006). *Discovering cell mechanisms: The creation of modern cell biology.* . Cambridge University Press.

Becvar, A., Hollan, J., & Hutchins, E. (2008). Representational gestures as cognitive artifacts for developing theories in a scientific laboratory. In M. S. Ackerman, C. A. Halverson, T. Erickson, & W. A. Kellogg (Eds.), *Resources, co-evolution and artifacts* (pp. 117–143). Springer Science & Business Media.

Bloch, M. (2008). Truth and sight: Generalizing without universalizing. *Journal of the Royal Anthropological Institute, 14*(S1), S22–S32. https://doi.org/10.2307/2803828.

Clark, A. (2006). Language, embodiment, and the cognitive niche. *Trends in Cognitive Sciences, 10*(8), 370–374. https://doi.org/10.1016/j.tics.2006.06.012.

Clark, A. (2008). *Supersizing the mind: Embodiment, action, and cognitive extension*. Oxford University Press.

Clark, A., & Chalmers, D. (1998). The extended mind. *Analysis, 58*(1), 7–19. https://doi.org/10.1093/analys/58.1.7.

Croft, W., & Cruse, D. A. (2004). *Cognitive linguistics.* Cambridge University Press.

Donald, M. (2010). The exographic revolution: neuropsychological sequelae. In C. Renfrew, & L. Malafouris (Eds.), *The cognitive life of things: Recasting the boundaries of the mind* (pp. 71–79): MacDonald Institute for Archeological Research.

Dunbar, K. (1999). The scientist in vivo: How scientists think and reason in the laboratory. In L. Magnani, N. J. Nersessian, & P. Thagard (Eds.), *Model-based reasoning in scientific discovery* (pp. 89–98). Kluwer/Plenum.

Ellen, R., & Fischer, M. D. (2013). Understanding cultural transmission in anthropology: A critical synthesis. In R. Ellen, S. J. Lycett, & S. E. Johns (Eds.). Berghahn Books.

Fillmore, C. J. (1997). *Lectures on deixis* (Lecture notes (book 65)). CSLI.

Goffman, E. (1978). *The presentation of self in everyday life*. Harmondsworth.

Gooding, D. C. (2004). Cognition, construction and culture: Visual theories in the sciences. *Journal of Cognition and Culture, 4*(3), 551–593. https://doi.org/10.1163/1568537042484896.

Goodwin, C. (1994). Professional vision. *American Anthropologist, 96*(3), 606–633. https://doi.org/10.1525/aa.1994.96.3.02a00100.

Goodwin, C. (2017). Environmentally coupled gestures. In C. Goodwin (Ed.), *Co-operative action* (pp. 221–242, Learning in Doing: Social, Cognitive and Computational Perspectives). Cambridge University Press.

Goody, J. (1977). *The domestication of the savage mind*. Cambridge University Press.

Hacking, I. (1981). Do we see through a microscope? *Pacific Philosophical Quarterly, 62*(4), 305–322. https://doi.org/10.1111/j.1468-0114.1981.tb00070.x.

Hacking, I. (1983). *Representing and intervening: Introductory topics in the philosophy of natural science* (Vols. 1 and 5). Cambridge University Press.

Hacking, I. (1992). The self-vindication of the laboratory sciences. In A. Pickering (Ed.), *Science as practice and culture* (pp. 29–63). University of Chicago Press.

Hindmarsh, J., & Heath, C. (2000). Embodied reference: A study of deixis in workplace interaction. *Journal of Pragmatics, 32*(12), 1855–1878. https://doi.org/10.1016/S0378-2166(99)00122-8.

Holmes, F. L., Renn, J., & Rheinberger, H. J. (2006). *Reworking the bench: research notebooks in the history of science* (Vol. 7). Springer Science & Business Media.

Howitt, S. M., & Wilson, A. N. (2014). Revisiting is the scientific paper a fraud? *EMBO Reports, 15*(5), 481–484. https://doi.org/10.1002/embr.201338302.

Hutchins, E. (2010). Cognitive ecology. . *Topics in Cognitive Science, 2*(4), 705–715. https://doi.org/10.1111/j.1756-8765.2010.01089.x.

Jacob, F. (1998). *Of flies, mice, and men.* Harvard University Press.

Johnson, M. (2008). *The meaning of the body: Aesthetics of human understanding.* University of Chicago Press.

Kirsh, D. (1995). The intelligent use of space. *Artificial Intelligence, 73*(1), 31–68. https://doi.org/10.1016/0004-3702(94)00017-U.

Kirsh, D. (2010). Thinking with external representations. *Ai & Society, 25*(4), 441–454. https://doi.org/10.1007/s00146-010-0272-8.

Kohler, R. E. (1994). *Lords of the fly: Drosophila genetics and the experimental life*. University of Chicago Press.

Koschmann, T., LeBaron, C., Goodwin, C., & Feltovich, P. (2011). Can you see the cystic artery yet? A simple matter of trust. *Journal of Pragmatics, 43*(2), 521–541. https://doi.org/10.1016/j.pragma.2009.09.009.

Latour, B. (1990). Drawing things together. In M. Lynch & S. Woolgar (Eds.), *Representation in scientific practice* (pp. 19–68). MIT Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge University Press.

Lévi-Strauss, C. (1964). *Totemism* (R. Needham, Trans.). The Merlin Press Ltd.

Levinson, S. C. (2003). *Space in language and cognition.* Cambridge University Press.

Levinson, S. C. (2008). Deixis. In L. Horn, & R. Ward (Eds.), *The handbook of pragmatics*. Blackwell Publishing.

Medawar, P. (1996). Is the scientific paper a fraud? In P. Medawar (Ed.), *The strange case of the spotted mice and other classic essays on science.* Oxford University Press.

Menary, R., & Gillett, A. J. (2016). Embodying culture: Integrated cognitive systems and cultural evolution. In J. Kiverstein (Ed.), *Routledge handbook of social mind*. Routledge.

Mody, C. C., & Kaiser, D. (2008). Scientific training and the creation of scientific knowledge. In E. J. Hackett, O. Amsterdamska, M. Lynch, & J. Wajcman (Eds.), *The handbook of science and technology studies* (pp. 377–402).

Myers, N. (2015). *Rendering life molecular: models, modelers, and excitable matter. Durham*. Duke University Press.

Müller-Wille, S., & Charmantier, I. (2012). Lists as research technologies. *Isis, 103*(4), 743. https://doi.org/10.1086/669048.

Ochs, E., Gonzales, P., & Jacoby, S. (1996). When I come down I'm in the domain state": Grammar and graphic representation in the interpretive activity of physicists. *Studies in Interactional Sociolinguistics, 13,* 328–369.

Ochs, E., Jacoby, S., & Gonzales, P. (1994). Interpretive journeys: How physicists talk and travel through graphic space. *Configurations, 2*(1), 151–171. https://doi.org/10.1353/con.1994.0003.

Øvergård, A.-C., Hamre, L. A., Harasimczuk, E., Dalvin, S., Nilsen, F., & Grotmol, S. (2016). Exocrine glands of Lepeophtheirus salmonis (Copepoda: Caligidae): Distribution, developmental appearance, and site of secretion. *Journal of Morphology, 277*(12), 1616–1630. https://doi.org/10.1002/jmor.20611.

Pitt, J. C. (2011). The epistemology of the very small. In J. C. Pitt (Ed.), *Doing philosophy of technology* (pp. 189–197). Springer.

Polanyi, M. (2005). *Personal knowledge: Towards a post-critical philosophy*. University of Chicago Press.

Rasmussen, N. (1993). Facts, artifacts, and mesosomes: Practicing epistemology with the electron microscope. *Studies in History and Philosophy of Science Part A, 24*(2), 227–265. https://doi.org/10.1016/0039-3681(93)90047-N.

Rheinberger, H. J. (2010). *An epistemology of the concrete: Twentieth-century histories of life*. Duke University Press.

Schickore, J., & Steinle, F. (2006). Introduction: Revisiting the context distinction. In J. Schickore, & F. Steinle (Eds.), *Revisiting discovery and justification: Historical and philosophical perspectives on the context distinction* (pp. 7–19). Springer.

Shore, B. (1995). *Culture in mind: Cognition, culture, and the problem of meaning*. Oxford University Press.

Slobin, D. I. (1996). From thought and language to thinking for speaking. In J. J. Gumperz, & S. C. Levinson (Eds.), *Rethinking linguistic relativity* (pp. 70–96). Cambridge University Press.

Steinle, F. (2003). The practice of studying practice: Analyzing research records of Ampere and Faraday. In F. L. Holmes, J. Renn, & H. J. Rheinberger (Eds.), *Reworking the bench* (Vol. 7, pp. 93–118, Archimedes (New Studies in the History and Philosophy of Science and Technology)). Springer.

Streeck, J., Goodwin, C., & LeBaron, C. (2011). *Embodied interaction: Language and body in the material world*. Cambridge University Press.

Yeo, R. (2008). Notebooks as memory aids: Precepts and practices in early modern England. *Memory Studies, 1*(1), 115–136. https://doi.org/10.1177/1750698007083894.