From Stimulus to Science: The Changing Nature of Visual Perception[·]

Wolff-Michael Roth, University of Victoria

ABSTRACT: Science is about knowing the world that surrounds and is perceptually accessible to each human being. It is generally assumed that science activities or demonstrations provide perceptual data (explained by theory to be learned) in a unique way. In this article, a detailed investigation into the phenomenology of visual perception is described, which draws on data from a scientific research laboratory, a tenth-grade physics course, and a first-person account of perception in unfamiliar terrain. The study shows the perceptual world (rather than being given in an instant) is historically constituted and mediated by actions, social processes, and tools. The results of this study have tremendous implication for teaching, for science educators can no longer assume that students perceive exactly those objects and events that they perceive and that the scientific concepts and theory (to be learned) explain.

You cannot count the bats in an inkplot because there are none. And yet a man—if he be ‘batminded’—may ‘see’ several. (Bateson, 1972, p. 272)

Without this ‘blurredness’ the limitlessness of visual space isn’t conceivable…. Now, is the imprecision of measurement the same concept as the imprecision of the visual images? I believe: Certainly not. (Wittgenstein, 1975, p. 268–269)

“A ‘bit’ of information is definable as a difference *which makes a difference*” (Bateson, 1972, p. 315, emphasis added)

1. INTRODUCTION

We know the world through our senses; among these, vision plays a central role, especially in the sciences (Edgerton, 1985). Yet the relationship between per-

[·] Paper presented at the annual meeting of the American Educational Research Association, New Orleans, April 1-5, 2002. All correspondence concerning this paper should be addressed to Wolff-Michael Roth, Lansdowne Professor, Applied Cognitive Science, MacLaurin Building A548, University of Victoria, PO Box 3100 Station CSC, Victoria, BC, Canada V8W 3N4. E-mail: mroth@uvic.ca

ception and (scientific) knowledge is not a simple one; there are nearly 2,000 years of investigations between Aristotle and Galileo, who produced the explanation that is still taught in high school and university courses. Constructing a particular type of understanding based on the human perceptual experience in and of the world, which subsequently becomes reified as the scientific canon, may be a long and arduous process. When a "scientific breakthrough" has been made, one often hears talk about "bringing light to the dark." That is, scientists grope their way in the dark, they explore without knowing where they are going; they construct teleological explanations about what they found and how they found it only after the fact (Suzuki, 1989). Scientific learning, therefore, has likeness with traveling new terrain in the dark, where the traveling itself (slowly) brings forth a heretofore-unknown world. In this paper, I contribute empirical evidence to the question how learners get "from [raw] stimulus to science" (Quine, 1995). I present evidence on the nature of perception from three rather different contexts—professional scientific research, tenth-grade physics, and my personal exploration of perception while travelling in an unfamiliar territory. In this phenomenological study, designed as a contribution to the project of understanding perceptual experience and the conditions that enable or constrain learning from this experience, I triangulate the different data sources to achieve a better appreciation and understanding of the relationship between perception and learning.

1.1. Scientific Perspective on Visual Perception

Neuroscientists describe vision in terms of the processes that unfold when light falls onto the retina. Between the retina and the visual cortex, there are many transformations that the original (retinal) stimulus undergoes. (Churchland and Sejnowski [1992] provide a good introduction to the topic.). In humans (as in all mammalian species), there are the photoreceptors in the retina, ganglion cells, ganglion cell axons (optic nerve), and synaptic transitions. At higher levels following the optical tract, neural activation is set in motion by the original stimulus passes through the superior colliculus, lateral geniculate nucleus, and optic radiations before reaching the visual cortex. However, vision does not only involve activation that travels from the retina to the visual cortex ("afferent" movement); rather, activation also travels in the reverse way ("efferent" movement) so that higher-level processes directly affect the photoreceptors (Jarvilehto, 1999).

Everyday understanding of visual perception and its psychological equivalent take the visual cortex to be something like a panoramic internal screen from which the conscious (Cartesian) "I" extracts the patterns of a given world (Pessoa, Thompson, & Noë, 1999). That is, the visual cortex is taken as the "mirror of nature" that underlies some epistemologies (Rorty, 1979). Such a view is implemented in almost all current cognitive models of learning from visual contact with the world (for an exception see O'Regan and Noë, 2001). For example, the cells in the visual areas are treated as feature detectors that extract from a visual array ("raw primal sketch") propositions like "there is an edge with coordinates (112,39), orientation 128°, contrast 82, and width 4" (Anderson, 1985, p. 31). More recently, researchers also use artificial neural networks to perform feature extraction and use gestalt principles to scan a visual buffer for structure and form (e.g., Tabachneck-Schijf, Leonardo, & Simon, 1997). But these newer models still presuppose the existence of features that are immediately given to the conscious mind. From this perspective, then, science students extract the patterns from the visual spectacles presented to them (e.g., in a demonstration) that create some patterns on their retinas. If they do not see what they are supposed to see, the problems are attributed to deficits in their minds.

Recent research in the neurosciences puts such conceptualizations into relief, by and large questioning the existence of the Cartesian observer who extracts patterns that can be represented in propositional terms (O'Regan & Noë, 2001). Thus, the very perception of objects changes with experience, though the role of experience in human perception has yet to be fully understood and there is mounting neuroscientific evidence that much of our perceptual apparatus is affected by learning (e.g., Wallis & Bülthoff, 1999). Seeing is hypothesized to be a way of learning how the world *is* from the individual's immediate apprehension of how the world *looks* (Noë, in press-a). There is increasing evidence that perceptual and motor systems are highly correlated (Decety & Grèzes, 1999); this evidence supports the hypothesis that the invariant structures of reality unfold in and through active exploration of appearances (Noë, in press-b). In this, neuroscientific research is consistent with views (and explicitly linked to previously developed insights) that had been analytically developed by phenomenological philosophers such as the late Ludwig Wittgenstein and Maurice Merleau-Ponty (e.g., Rizzolatti, Fadiga, Fogassi & Gallese, 1997).

1.2. Phenomenology of Visual Perception

Phenomenologists point out that we always perceive from a first-person perspective, from the inside so to speak (Merleau-Ponty, 1945). Perception is not merely embedded in an abstract world full of constraints; perception actively contributes to the forthcoming of a world through the movements of the person (Varela, Thompson, & Rosch, 1993). This world, for the individual, is not the same as that measured and explained by scientists (von Uexküll, 1973). Thus, "[w]hat the world *is* to the organism depends on what the organism is doing and might do next" (Clancey, 1997, p. 257), and, most importantly, what it has done in the past. At the same time, we do not have to reconstruct objects from first principles based on visible appearance; our knowledgeable interactions with things are facilitated by their functionally significant perceptual properties or gestalts (Agre, 1997). How this works is largely unknown—but it would be a mistake to assume a simple context-independent mapping between perceptual features and the things so perceived.

One of the most important findings of phenomenological inquiry is the vagueness, blurredness, indeterminacy, and indistinctness of the visual field: there are no such things as visual images of precisely 24 or 25 pencil marks, 100-gons and circles, or gaggles of 100 geese (Wittgenstein, 1975). This vagueness, blurredness, indeterminacy, and indistinctness of the visual field, rather than being a problem, has to be taken as an irreducible and a-priori feature of perception; it has to be taken as a positive phenomenon (Merleau-Ponty, 1945). This phenomenon has been the focus of research in phenomenological studies of perception: building on Gestalt psychological principles, this research articulates perception in terms of the dialectical unit of figure-ground. The simplest perceptual entity is not a sensation but a relatively precise figure floating over a more indistinct ground. The figure-ground structure of perceptual experience is an invariant of perception, known to be such prior to phenomenological reflection (Pessoa, Thompson, & Noë, 1998).

1.3. First- and Third Person Accounts of Visual Perception

The methodologies and results of psychological and phenomenological research on perception described are quite different. Many current psychological models take an intermediate level between neuroscientific and phenomenological inquiry. However, there are suggestions (including those by philosophers, physicists, and mathematicians) that such an intermediate level for explaining perception is not necessary (e.g., Churchland, 1995; Hut, 1999; Petitot, 1994). It is suggested that a fruitful approach lies in bridging directly between neuroscientific and phenomenological studies of human experience (Varela, 1996).

We live in worlds that come forth from our actions; we learn as a function of the events and our encounters with the objects in these worlds rather than in scientific, third-person worlds. To understand learning as it arises from individual, subjective experience, we need systematic phenomenological inquiry; the results of such inquiries can then be correlated with those from neuroscientific research. At present, however, scientific (psychological) approaches almost always take third-person perspectives. One of the reasons for the reluctance to adopt a first-person perspective lies in the fact that phenomenological inquiry is charged with being “introspective,” “fluffy stuff,” and “extremely subjective.” This, however, is an inappropriate view. The real aim of phenomenological inquiry is the articulation of experience in terms of concrete universals, which manifest themselves in the particularities of all members *without* exception (Il'enkov, 1982). First-person (subject-centered) approaches therefore develop (psychological) concepts that are concretely applicable to every single human being (Holzkamp, 1991). In this study, first- and third-person descriptions are used to constrain one another and are mutually harmonized. The overall result of such an approach is the movement toward an integrated and global perspective on human cognition in general (Varela & Shear, 1999) and perception in particular.

2. RESEARCH DESIGN

2.1. Contexts and Data Sources

To mutually constrain and harmonize first- and third-person descriptions of perceptual phenomena, the data in this paper derive from three very different contexts, evidence that the perceptual phenomena described are prevalent not only within one context but also across contexts. The present data were collected in a biology research laboratory, a tenth-grade German high school physics class, and my own formal first-person inquiries regarding perception. Here, I provide brief, general descriptions of the participants, contexts, and data sources; specific information is provided in the context of each case study that appears in the subsequent section.

Biology laboratory: For the past 18 months, I conducted ethnographic research in an experimental biology laboratory that focuses on vision in salmonid fishes; Greg and Tony are the lead biologist and research associate, respectively. As part of a large project concerned with finding alternative revenue sources for coastal communities, they gather data on the physiological changes in salmonids to different salmon hatcheries to provide better estimates as to the most appropriate time for releasing the smolt that have been hatched in each facility. In this ongoing study, I participate in the lab and in the field to study the changes in local (hatchery, lab) practices as knowledge is being exchanged between the hatcheries and the lab. I engage in doing ethnographic fieldwork, recording laboratory activities in real time (using a digital, night-vision-capable camera because all operations in the lab have to be conducted in near darkness), recording data discussions sessions, and collecting artifacts created (e.g., draft papers, initial SPSS data analysis, and email exchanges).

Tenth-grade physics course: During my stay at the Hanse Institute of Advance Studies, Manuela Welzel provided me with access to a set of classroom video collected as part of her dissertation (Welzel, 1995). She had taught a tenth-grade physics course on static electricity. Physics was taught during two 45-minute lessons per week. The entire unit was videotaped using two fixed cameras that focused on one group each, yielding a total of 30 hours of videotaped materials (2 cameras x 20 lessons/camera x 0.75 hours/lesson). Two microphones recorded the conversations around each of the two tables. The videotapes were transcribed including descriptions of the actions in which students engaged. Students were formally tested at three points in the unit, after Lesson 8 (week 4), Lesson 20 (week 10), and Lesson 30 (week 15). These tests were copied and entered in my database. They served to assess students' understanding and for conducting statistical analyses. The eight students featured in the videotapes were interviewed prior and after the unit. These interviews were transcribed and analyzed in terms of student understanding of concepts in static electricity. Furthermore, all instances where students used gestures as part of their communication were digitized to make them available for frame-by-frame analysis. The respective part of the sound track and transcript were also prepared as previously.

First-person inquiries into perceptual phenomena: For a three-month period (during my stay as a research fellow in the neurocognitive sciences at the Hanse Institute of Advanced Studies, Delmenhorst, Germany, I conducted "perceptual experiments" and kept detailed records about perceptual phenomena from a first-person perspective. For example, one of these experiments involved more than 20 bicycle rides through an initially unfamiliar part of the countryside near the Institute. After each ride, I recorded all features of the countryside that I could remember. Sometimes I stopped to record particular perceptual phenomena that occurred during the ride. These notes and the theoretical and methodological commentaries made at the same time became data for the subsequent analysis presented here.

2.2. Data and Analyses

Starting with the initial word-for-word transcriptions, I prepared detailed transcriptions: utterances, overlaps between two individuals, gestures, and pauses are measured to 0.1-second accuracy and included in transcript. (The two software packages used in this study, Ulead® MediaStudio Pro 5.2 and iMovie allow replaying the sound track at slow rates, which aids the measurement and recording of overlaps.) In many cases, the video images were copied and coordinated with the transcript. Thus, for the physics videotapes from the tenth-grade physics course, I spent approximately 350 hours viewing the database, digitizing all situations in which students or teacher used gestures, and manipulating the sound track to improve audibility and transcription. These transcriptions were then transformed to contain images and time codes. I prepared visual represen-

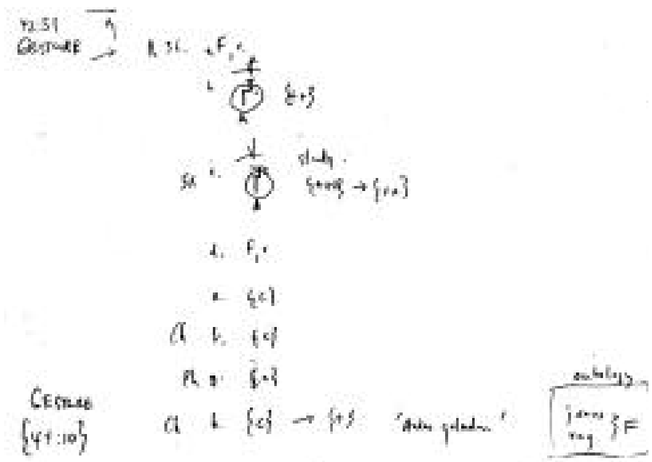


Figure 1. *Excerpt from the analysis of the tenth-grade physics lesson. This sequence (#36) begins 42' 51'' into the tape and ends 1' 19'' later (44' 10''). Two students (Ph, Ch) use one of two materials (F = {jeans, rag}) to rub (r) a transparency film (36.a, 36.d), which they move toward and away from an electroscope (36.b, 36.e–h). The needle of the electroscope shows (e.g., {++}) or changes (e.g., {++} → {+++}) its deflection. Each student action in both groups and for the entire 20-lesson unit was coded in this way.*

tations of the episodes, paying particular attention to the entities that were behaviorally relevant in students' actions and talk (Figure 1). That is, this part of the analysis reconstructs (as far as this is possible) the students' lifeworld rather than presuming that they attend to the structures salient to scientists or science educators. (Whether the students attend to an object or event in a particular way has to be shown rather than taken for granted.) The notes maintained with respect to my first-person inquiry were not transformed but directly became the basis of the subsequent analytic process (phenomenological reduction).

The present analyses are grounded in reflexive hermeneutic phenomenology, which insists on three issues central to the present research (Ricœur, 1991). First, interpretation of human action and its setting requires both explanation-seeking structural analysis and understanding-seeking lived experience. Second, human actions are subject to the same analytic processes as text; that is, hermeneutic phenomenological analysis is extended to ephemeral actions captured here on videotapes. Third, the analysis of the data has to be reflexive, that is, it has to be applicable to the analytic process itself. With respect to the analysis from the physics class, Manuela Welzel functioned as a “disinterested peer” (Guba & Lincoln, 1989) who repeatedly to discussed with me and critiqued my emerging concepts and assertions. I tested these assertions in the entire set of episodes.

First-person descriptions of experience, which constitute but an experiential leading clue, were analyzed by means of phenomenological reduction, which involves three phases: suspension of habitual thought, conversion of attention from things in the world to representations, and receptivity towards the experience. (A good description of the structural dynamics of the act of phenomenological reduction [becoming aware] can be found in Depraz, Varela, and Vermeersch, 2000.) Practically, the method of reduction is a matter of reiterating successive personal experiences separated in time until the main traits of experience points themselves out (Varela & Depraz, 2000). The sought-for results of this method of inquiry are therefore concrete universals that transcend the private nature of experience and yet account for it (Varela, 1996).

Initial conceptualizations, pertaining both to the physics class and to my first-person inquiries were presented to different groups of colleagues and graduate students at the University of Bremen and at the Hanse Institute of Advanced Studies. Critical analysis and feedback led to further refinement of the analyses.

3. THREE CASE STUDIES OF PERCEPTION

In studies of knowing and learning, visual perception is usually taken as unproblematic and taken for granted. Thus, in educational teaching and research practice, it is commonly assumed that students perceive what they are supposed to perceive (e.g., in a practical or paper-and-pencil “problem”). This assumption, as specifically designed classroom research has shown, is not warranted (e.g., Roth, McRobbie, Lucas, & Boutonné, 1997); it is not warranted even when the individuals are highly trained scientists looking at a graph from an undergraduate textbook (Roth, Bowen, & Masciotra, 2002). In this section, three case studies are presented in which I am involved in different ways—as observer-participant (biology research laboratory), distant observer (tenth-grade physics), and as central subject (phenomenological inquiry). Each case study features perceptual phenomena that are prevalent within and across data sets, which is evidence for the pervasive nature of these phenomena. Because there are any number of episodes that I could have chosen within each set of data to support my findings, I made the particular choice of episodes on pragmatic grounds. Thus, the episodes were selected to be illustrative and provide easy access for those unfamiliar with particular (science) content.

In this section, I provide evidence that support several hypotheses stated in the introductory section. Thus, my data show that perception cannot be equated with the stimuli that fall onto the retina. We lack visual awareness of all but a few aspects of the visual scene, particularly during a first-time-through experience but again when we are very familiar with the scene. Through active exploration of the scene (moving eyes, manipulating [parts of] it manually, moving about), we come to perceive things for the first time and how they are apart from the way they look. Seeing is a process that presents us always with the looks of things but, when we see a thing *as* "something," this "something" is different from the way it looks. Perception is therefore an experientially conditioned historical and contingent process rather than a transparent window on a stable world. Although we are initially not aware of many features (they are immanent), behaviorally relevant features become conscious (transcendentally present) especially during moments of breakdown and when there are contradictory observations.

3.1. Articulation of the Perceptual Field

In this section, I provide a first-person account of how one becomes perceptually aware of things in the world. First, we move about (walk, drive, ride a bicycle) without being aware of most of the surroundings; even if I am attuned to and visually track the surroundings, I am not *aware* of most features. Second, when I look at a particular scene for the first time, my perceptual field is not automatically and self-evidently articulated. Third, although I seem to perceive "everything," I continue to become aware of new entities during subsequent experience. Relevant figure-ground separations emerge from extended experience, familiarity with the situation, and are spurred on by issues of behavioral relevance. That is, perception is articulated in the course of moving about (experience). Articulation, here, has a double sense. On the one hand, articulation is the location where joints occur in an indeterminate perceptual field, that is, where a determinate perceptual figure separates from an indeterminate ground. This separation is associated with experience: with our actions, lifeworlds come forth. On the other hand, articulation refers to the verbal naming of the perceptual figure (gestalt). Those entities that have become perceptually isolated from the ground and have become figure can be named, pointed out, or described in propositional form (observation sentences).

3.1.1. Context of the Episodes

For years, I have recorded the unfolding of critical problem-solving events in my life, paying particular attention to avoiding after-the-fact rationalizations while describing and explaining events. The purpose of these recordings is to capture—to the extent that this is possible—the first-time-through nature of problem solving and particularly the perceptual processes involved. The database used here was generated during a three-month fellowship that allowed me to (a) conduct the initial analyses of the tenth-grade physics videotapes and (b) record my own perceptual processes during “experiments” and during the data analysis. As I analyzed the physics tapes, it became evident to me that students faced some fundamental questions, “What is it that I am supposed to see?” and “Do I see what I am supposed to see?” To better understand the students’ experience of learning about static electricity by producing unfamiliar events, I conducted several “experiments” to reproduce the effect of perceiving something for the first time. During and after each daily bicycle trip into the surrounding countryside, I recorded perceptions, salient entities, and striking realizations, that is, anything that appeared to pertain to perceptual phenomena.

3.1.2. Two Episodes

Episode 1. The analysis of the present episode shows that the perceptual field is to be understood as indeterminate (not only on the periphery but also in the center of vision). Whereas the world is perceptually experienced, specific features only emerge into consciousness with extended experience. The world is not given once and for all, in a monothetic way, but unfolds, continuously changing whole-part relations as ever more figures come to stand against the ground. Our world—that which is relevant to our thoughts and behavior—is brought forth through our experience of moving (eyes, hands, body).[1]

Day 1. As I was riding along, I was aware of my surroundings (trees, flowers, and so forth) without really focusing on anything in particular. Although I was aware at the moment, here at home, I remember few things in particular, few stretches of the trip. But those things I do remember are associated with a particular type of experience. There were things, like a particular house or a road sign (“Landwehr”) that was pulling my gaze to take a closer look. As I focus, sometimes with considerable delay, a memory surfaces—the house looks like the one I had lived in 40 years earlier, “Landwehr” was the name of a professor and of a street in the city where I went to university. [E01p7–8]

[1] The following excerpts are keyed to their location in the database to provide an audit trail (Guba & Lincoln, 1989), which is a constitutive practice of quality in interpretative research.

Day 2. As I am riding along, there are features in the environment that I have not remembered yesterday at home after the trip, but which I nevertheless re-cognize the moment I approach them. As I come around the Y-fork, I re-member that I had seen from here the child on the bike and with the dog ahead of me. They then turned into the farm some 200 meters further on. I re-member the field with the freshly sprouting grain plants though I had not remembered them at home. Thus there are things that despite the complexity of the experience, I re-cognized even before I reached the place, that I started to anticipate when I got within reach. But then there were other farms, other signs, other features that I seem to see for the first time…. [E01p15]

Today (my fifth) *trip, I notice for the first time the little plates, inscribed with numbers that increase by 0.1 about every 100 meters. I infer that these are distance indicators with reference to some starting point. [E01p31]* (I subsequently found the starting point during an explicitly planned trip.)

Today (my seventh) *trip, I notice for the first time the upper parts of two gigantic towers that are visible above the treetops. [NBp13]* (From then on, I not only saw the towers each time I came by this place, but I was expecting them to show up even before I got to the place.)

The movement of the body with respect to the surroundings and of the eyes with respect to the body is so central to the experience that it is easily overlooked. The data show that I am *perceptually tuned* to my surroundings, which enables me to move about, my perception is indeterminate: initially, few features come to stand as figures against the ground, to be remembered subsequently. Before my awareness grasps detailed features, the physical world appears to exist, indistinct, and as invitation to be articulated. I remembered few concrete things after the first and even subsequent trips along the same route. However, in the course of the repeated experience, new features emerge into consciousness; I see the sign with the “Landwehr” inscription, the distance signs, and the towers for the first time.

Despite the self-awareness that the experiment is about recalling the maximum number of features and despite an extended effort to recall as much as possible. Each time I perceive a new feature “for the first time,” my world becomes more (perceptually) articulated, allowing me to articulate it (verbally) in my notes. At the same time, certain entities (e.g., the “Landwehr” sign) have a certain “grabbiness” (O'Regan, 2001), which turns out to be related to (and is articulated in terms of) previous experience. They bring forth an experience of déjà vu, including specific details (features) that come to stand as figures against ground. The descriptive articulation follows the perceptual articulation.

Episode 2. When I first perceived the two towers, it was not as if they slowly emerged into my consciousness. Suddenly, they were there. It was then that I began to wonder why I had not seen them on the six previous trips. From that point on, they were so obvious to me; in fact, I treated them as having been there all along; yet in my experiential world, they had not existed and therefore would not have shown up in assessments of my knowing and learning. I saw these towers every time that I passed this particular part of the road only subsequent to the seventh trip. That is, the two towers existed *immanently* (they were there for me to be discovered although I did not perceive them) and *transcendentally* (I take them to have existed before they appeared as concrete objects in my life). While individual objects burst into my consciousness, the consciously experienced landscape as a whole grew proportionally with the sum of these bursts. But these objects were all over the landscape; bits and pieces came to stand out against and held together by the indeterminate ground.

In the first episode, I pointed out the sense of déjà vu that comes with some experiences. Whereas one may have had an awareness of something, it has not influenced conscious thought or practical action. This something is diffusely noticed but is of no behavioral relevance. We therefore cannot say to have seen something, for this would imply that we not only track an environmental feature and exercise mastery of sensorimotor capabilities but also that we integrate these with our capacities for thought and action-guidance (O'Regan & Noë, 2001). Awareness and integration with thought is often triggered, as in this episode, by situations of breakdown.

I ride a long the road and jump with my bike off of the bicycle path and onto the road. As I land, my rear tire explodes and is flat faster than I can come to a halt so that I roll on the rim for a while. I take the wheel off, remove the tire, remove the inner tube and inspect it. It has a long tear, about 8 centimeters. I cannot fix it with my little kit, and I have left my spare inner tube at home. I leave the inner tube in place by not removing the valve. I inspect whether in the region of the tear there are spokes coming through the lining, for the tear seems toward the center, on the inner part of the tube.

I walk back to town and get a new inner tube. While placing it back, I notice that some of the tire wall had come detached from the wire that goes under the rim. I wonder whether I should go back into the department store and get a new tire. But I decide to buy one in the big specialty store in the nearby city where I might get something that is just like the one I have—it is not a pressing issue. I mount the inner tube, inflate it enough by hand to ride comfortably. I ride the 4 kilometers to the next gas station on my way. As I inflate the tire, it explodes. I notice that the tire has a tear. I expect the inner tube to be torn at that place.

"I put the pieces together." The inner tube had protruded through the place where the wall had come off the tire and exploded when I jumped off the bicycle path. It exploded again when I put a lot of pressure. [E02p12]

In this situation, the tear in the tire wall became salient as tear and therefore behaviorally relevant only after the second blowout. Initially, there merely was a “diffuse noticing.” In fact, that I had “diffusely noticed” became evident to me only at the gas station when the inner tube blew for the second time. I had perceptually tracked the tire but not integrated the perceptual capacities with those for thought and action-guidance. That is, I had not perceived (seen) the tear *as tear*. Even the question whether to buy a new tire at the instance or later was but a fleeting, indeterminate idea rather than a concrete deliberation of alternatives. Now I know that the tear existed immanently, as something possibly to be grasped. It is at this point that the tear became salient as a tear, a figure against the indeterminate ground of everything else. Simultaneously, an association between explosion and tear appeared to me. It is at this point that the thought “I should have known it” arose; I took the tear as transcendentally existing before I became consciously aware of it. Whether an impression or initial noticing is something that we need to focus on and attend to arises from its covariation with other aspects in our perceptual field; this covariation is intimately tight to sensorimotor activity (at minimum, eye movement to focus on one than on another aspect). My initial perceptual experience, while leading to an impression, was not a difference that made a difference (Bateson, 1972).

3.1.3. Discussion

The analysis of the two episodes makes salient three key features of visual perception. First, perception is intimately tied to exploration. Second, perception requires mastery of sensorimotor contingencies (at a minimum, exercise of eye muscle for focusing and changing orientation). Third, seeing something *as something* requires an integration of visual tracking the surroundings with capacities for thought and action-guidance.

This investigation of my perceptual experiences while riding a bicycle through initially unfamiliar surroundings shows that the world is not given to me the instant that I first lay eye on it. Rather, following extended experience, different figure/ground relations (e.g., “Landwehr,” towers, and distance signs) manifest themselves as they emerge from an indeterminate perception. This result was further underscored by the second episode, which showed that I may be vaguely aware of something without that it exists as a behaviorally relevant entity. The tear did not exist as a reportable and relevant “fact” in my lifeworld until the second blow out; I therefore could not have stated an observation sentence and even less an observation categorical (generalization of observation sentences [Quine, 1995]). If an all-knowing teacher had set up the tear (or the towers, distance signs, etc.), I would have failed to demonstrate knowledge or failed to learn from the experience, for during the first (and until the n-th) encounter, the entities were not salient to me. I did not attend to these entities that the teacher expected me to see. As a result, I would not have understood whatever explanation the teacher provided for what I should have (but have not actually) seen.

The present analyses suggest that a salient figure over indeterminate ground is an emergent feature. Sometimes, this emergence is provoked by some sort of breakdown (as in the tire example). That is, I discover a feature of something (fact, object, tool) not by looking and ascertaining properties but by taking note of co-varying figures (tear, explosion) in the course of use/ experience (e.g., Heidegger, 1996). To take note of covariation requires orienting to and focusing on a minimum of two figures, that is, it requires (repeated) sensorimotor activity. When I discover that the object (tire) can no longer be used, or that some fact does not fit my expectation, the entity (tear) becomes conspicuous. Conspicuity, visual awareness, means that thought (expectation) is integrated with conscious visual tracking of my surrounding.

In the writing of this section, I explicitly attended to the way in which agency is represented. It is important to the understanding of perception that I did not "construct" the towers, the distance and "Landwehr" signs, or the tear. These things were thrust into my consciousness. I did not "construct" the relationship (covariation) between tear and explosion; the relationship emerged, without my (conscious) doing, and then was there. That is, I had no conscious control over the things that would appear and become conscious.

3.2. Emergent Features of a Glow Lamp

In the first case study, I showed that objects and situations are not given to me in the instant I glance at them; nor are they given in propositional form, as observation sentences and even less as observation categoricals (generalizations). Finally, perception was intimately tied to exploration. In this second case study, I show how even a simple thing such as a glow lamp acquires its distinguishing features while students use it extensively as part of their investigations. Thus, the structure of the filament, the composition of the housing (glass, metal ends), and the context-sensitive location where it glows are not perceptual aspects once students "lay their eyes on" and "look at" or "glance at" a glow lamp (Figure 2). All these features emerge in the process of the investigation and within the context of many other figure-ground relations. I observed such emergent features time and again on the tenth-grade physics tapes, including the structure and composition of coated pith balls, coated table tennis balls, electroscopes, or coated roller blinds. (These observations were confirmed in another set of tapes showing eleventh-grade physics students in hands-on experiences with the same materials and instruments.)

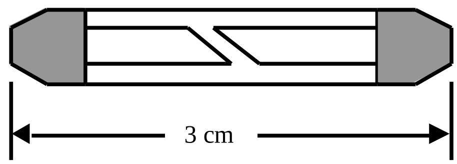


Figure 2. *A representation of the glow lamp used by the students. This representation does not correspond to the students' actual perceptual experience (Wittgenstein, 1975), which did not (a) distinguish (in action or by description) between glass and metal ends, (b) note the gap in the filament, or (c) remark that the light appears left or right depending on the context.*

3.2.1. Context of the Episodes

Throughout the unit on static electricity, students were provided with opportunities to explore static electric phenomena by means of hands-on activity (sensorimotor exploration). In the present episodes, as throughout the course, students had available different materials and objects including transparency films, metal plates, pieces of wool and cotton cloth, small neon glow lamps, metal coated elderberry mark balls, metal coated table tennis balls, and (plastic, metal, PVC) rods. The teacher (Manuela Welzel) had demonstrated how rubbing objects against other objects created certain effects that made a glow lamp light up or attracted elderberry mark spheres and table tennis balls to the objects. The teacher invited the students to conduct open investigations of different materials and asked them to find out (record) as much as they could. The present episodes were taken from the videotape showing four young women (Brita, Clare, Iris, and Jenny).

3.2.2. Three Episodes

Episode 1. In the course of the first 45-minute lesson, the four students brought into contact (rubbed, pulled past each other, or re-used previously rubbed materials) two materials and subsequently tested them for charges 162 times (see excerpt in Table 1). In some situations, they commented in some way upon the outcome ("it worked," "it didn't work"), thereby providing an indication of what they had seen, but in other situations, no comment was provided. The excerpt from the investigation in Table 1 shows that after bringing two materials into close contact sometimes brought about an effect (from the observer perspective) and sometimes it did not. Of particular interest here are those experiments that involved the glow lamp (highlighted in the table). Students attempted repeatedly to re-do the experiment presented earlier by the teacher. However, whatever they did and whichever materials they used, the bulb initially did not glow other than in trial A21 (Table 1). When the teacher passed their table after trial A38, the students indicated that the bulb was not working.

Brita:	With this one, it doesn't work.
Teacher:	What's wrong? It doesn't work? What could be wrong so that it doesn't work?
Jenny:	The lamp is broken! It is broken.
Teacher:	What is broken? The transparency?
Jenny:	Yeah. Perhaps it's the pants.
Teacher:	(*Pulls transparency through clasped knees, tests transparency with glow lamp: it glows.*) Did you see it?
Iris:	Yeah, you could see it.
Brita:	What brand of pants do you wear?

That is, from their experiments with the bulb, they concluded at this point that it was the bulb that did not work (i.e., a breakdown). The teacher then provided a demonstration involving the transparency (drawn through her clasped jeans-covered knees) and the glow lamp. She held the lamp to the transparency, which made it glow. Jenny tried to copy the teacher but in her trial (A39), the lamp did not glow. Iris repeated the procedure, which made the lamp glow (trial A40, A44); Jenny and Clare tried again (trials A41–A43) but failed to make the lamp glow. The students continued to fail to make the lamp glow and attributed the failure (breakdown) to the materials they used, the manufacturer of their pants, transparency films that were "worn out," and so forth. A new series of attempts (trials A53–A56) did not work for Iris (who had made a successful attempt earlier on). Here then a new question posed itself, why was she successful initially and later experienced failure?

Brita was the first to make a significant discovery about the glow lamp. She repeated the teacher's demonstration (trials A116–A117). As the group had just written down the conclusion that the experiments do not work with old (i.e., used) transparency sheets, Brita suggested doing it over again using a new one.[2] As she got the lamp, she fixated it. She gazed intently at the lamp (1.8 seconds), then put it back on the table and got another lamp. She then pulled the transparency through her clasped knees, took the second lamp, intently looking at it again (1.3 s), and then tested the transparency. The bulb did not glow. Brita looked again intently at the lamp (1.0 s), and then asked the teacher, "Is it not

[2] When I first saw the scene, I smiled because the proposition appeared outlandish. Several days later, reproducing some of the students' experiments using the same materials, I found myself stating the same hypothesis, transparencies "wear out," and found confirmation in subsequent trials with a new, unused transparency.

Table 1: Excerpt from the investigation of static electricity in one student group

Person	*Trial*	*Material 1*	*Material 2*	*Action*	*Test Object*	*Observation*
Iris	A20	Transparency	Ruler	Rub hard	Styrofoam	-
Clare	***A21***	***Transparency***	***Pants***	***Pull***	***Bulb***	***Light***
Iris	A22	Transparency	Rag	Rub	Styrofoam	+
Iris	A23	Transparency	Rag	Rub	Styrofoam	+
Iris	A24	Transparency	Rag	Rub	Styrofoam	-
Iris	A25	Transparency	Rag	Rub	Styrofoam	-
Iris	A26	Transparency	Rag	Rub	Styrofoam	+
Jenny	A27	Transparency	Ruler	Rub	TT ball	+
Jenny	A28	Transparency	Ruler	Rub	TT ball	+
Jenny	A29	Transparency	Ruler	Rub	TT ball	+
Jenny	A30	Transparency	Ruler	Rub	TT ball	-
Jenny	*A31*	*Transparency*	*Ruler*	*Rub*	*Bulb*	*No light*
Jenny	*A32*	*Transparency*	*Pants*	*Pull*	*Bulb*	*No light*
Jenny	*A33*	*Transparency*	*Pants*	*Pull*	*Bulb*	*No light*
Jenny	A34	Transparency	Ruler	Rub	Styrofoam	-
Brita	A35	Transparency	Rag	Rub	Bulb	No light
Clare	A36	Transparency	Ruler	Rub	TT ball	-
Jenny	A37	Metal	Ruler	Rub	TT ball	-
Brita	*A38*	*Transparency*	*Rag*	*Rub*	*Bulb*	*No light*
Teacher		*Transparency*	*Pants*	*Rub*	*Bulb*	*Light*

Note: Students either rubbed two materials, sometimes pressing hard (e.g., A20). One material, here listed as “Material 1” was subsequently tested using a variety of test objects. Any student observation expressed in an utterance would be coded as “OA” in the “trial” column.

broken? Because this is not connected on the inside?” This is the first time that a student (verbally) articulated the internal structure of the glow lamp (Figure 2). This articulation was associated with two experiments that had not worked (breakdown) and the close inspection of two lamps that exhibited gaps between the two ends of the filament.

Episode 2. Two lessons later (Lesson 3), Jenny made a second significant discovery. It began with a sequence of tests (Table 2), in which she commented on the outcome of a test (no light) by saying, “I am sorry, but there is nothing I can do.” In trial A7, Jenny held the bulb indistinctly, possibly partially on the glass. In the next trial, she tied a string around the body of the lamp and then, holding the string, brought the lamp to the charged object—no effect. During trials A12, A13, and A15, the videotape shows Jenny holding the lamp on its metal end. She noted that she heard a bristling sound but that the bulb did not light. In the demonstration to Brita, she claimed to have seen the lamp glow, but Brita remained unconvinced.

Table 2: *Excerpt from the investigation of static electricity in one student group*

Person	*Trial*	*Material 1*	*Material 2*	*Action*	*Test Object*	*Observation*
Iris	A6	Transparency	Pants	Pull	Bulb	-
Jenny	A7	Transparency	Rag	Rub	Bulb	-
Jenny	A8	Transparency	Rag	Rub	Bulb on string	-
Jenny	A10	Transparency	Rag	Rub	Bulb	-
Jenny	A11	Transparency	Rag	Rub	Bulb	-
Jenny	A12	Transparency	Rag	Rub (VERY long)	Bulb (tests all over)	-
Jenny	A13	Transparency	Rag	Rub (VERY long)	Bulb (tests all over)	-
Jenny	A15	Transparency	Leather	Rub (VERY long)	Bulb (tests all over)	+ {?}
Jenny	A17	Transparency	Leather	Rub (VERY long)	Bulb (tests all over)	+ {?} Brita not convinced
Jenny	A21	Transparency	Leather	Rub (transp. on table)	Bulb	-

Note: Same as Table 1

Iris then got another lamp from the supply area and conducted several tests, each time claiming to have heard a crackling noise from the lamp. Jenny also did another attempt (Table 2, A18) and then announced that she had made it work ("Hey, it worked! Yeah, it worked!"). However, she was unsuccessful on subsequent trials (e.g., A21 [Table 2]). Several minutes later, Jenny excitedly called the teacher ("It works, it just worked, Mrs. Welzel!"). As the teacher approached, the following conversation ensued.

Teacher: Did you establish what was going on with the glow lamp, the fact that it didn't work?

Jenny: Of course! (*She takes a glow lamp*.) You must not hold it like this. (*Holds the glow lamp between two fingers in the center, i.e., on glass*.) But you have to hold it like this. (*Holds the glow lamp with thumb and index finger at metal end*.)

Teacher: Exactly! (*Leaves table*)

Jenny: (*Places glow lamp on table*.)

Iris: How do you have to hold it? (*She picks up the glow lamp, holding it between thumb and index finger*.)

Clare: How do you have to hold it? On the metal thing, ha? Or?

Jenny: (*Takes the glow lamp from Iris, brings it right in front of Clare's face*.) Like this, you have to hold it like this (*holds glow lamp at metal end*) and not like this (holds glow lamp in center). (*Returns glow lamp to table*.)

Clare: (*Picks up the glow lamp and holds it between thumb and index finger on one metal end.*) Like this, yes?

Jessica articulated for the first time what needed to happen for the lamp to glow, "You must not hold it *this* way, but you have to hold it *this* way." The difference was expressed in the contrast of "Not … this way, but … this way" and the associated change in the position of her fingers on the glow lamp. From the utterance and the corresponding gesture, Caren was to infer what the core difference was that Jessica wanted to express. Caren tested whether she had actually perceived and therefore understood what was the important difference. (The difference might have also been in other observable differences that were *not* deemed relevant in *this* situation; e.g., the shape of her grip was not the same.) That is, she tested whether the difference perceived was making the difference, and therefore a bit of information.

Episode 3. A third important feature of the glow lamp was discovered 10 lessons later when the students were asked to test a pair of metal plates that had been charged by induction while in contact and then separated. In their investigations, students initially simply noted that the lamp glowed. Upon the insistent questioning of the teacher, students eventually came to notice that the lamp sometimes glowed at the filament close to their hands, sometimes at the opposite filament. That is, although the side of the lamp where the glow is observed had changed during their investigations, this difference became salient for the first time after 13 lessons of creating and investigating charged bodies.

3.2.3. Discussion

In the course of the three episodes, the glow lamp emerged as a lamp characterized by specific, articulated properties. It now had a filament consisting of two short discontinuous piece, had to be held at the metal ends to "work," and the glowing occurred at the filament close to the hand or away from it. It is true that students may have been vaguely aware of the glass body and metal ends much in the same way that I had vaguely noticed the tear in the tire. Asking students to draw the lamp may even have led to a diagram such as Figure 2 (seeking relevance in the question, students may have articulated certain aspects). Even if they had perceptually attuned and visually tracked the lamp, the features did not make a behavioral difference. The students did not integrate this with thought and action-guidance and therefore did not see the feature of the lamp (O'Regan & Noë, 2001).

When students began using the glow lamp, they treated it holistically as something that glows or does not glow. The glow lamp had a tool function as an indicator of the presence of static electricity. There is no evidence that the students perceived the properties/aspects x_1, x_2, … x_n of the lamp just by looking at it and (initially) using it. Rather, the features of the glow lamp arose in the course of students' investigations much in the same way that the towers or tear in the tire became part of my lifeworld through repeated experience. The relation between the lamp as a whole and its parts arose while students *explored* the fact that "it didn't work" (breakdown). Students' articulation of glow lamp features was occasioned by an equipment breakdown much as my own articulation of the tear was occasioned by the second tire blow out. Other covariations that appeared to exist (type of jeans, materials, worn-out transparencies) were discarded when tests with elderberry mark spheres showed indeed some effect.

A number of colleagues who observed these episodes made depreciative (deficit-based) comments about the students, who apparently repeated "the same things over an over again" without being able to get the investigation to work or find out why it did not work. (Other colleagues observing similar tapes have made equally depreciative comments about students how did not see what they were supposed to see.) These colleagues blamed students for not "looking carefully" at the glow lamp and for not seeing its self-evidently present aspects (whole-part relation, metal ends, filament, relation between material and side that glows). I suggest that these colleagues make these attributions because they do not deal with perceptual experience from a first-time-through and first-person perspective. For example, I noticed neither the structure of the filament nor the differences in location where the lamp glowed:

When I rubbed the sheet and held the glow lamp to it, I did not see at first that it was lighting up. I did not see what, from a physics perspective, I was supposed to see—and this although I am a physicist by training. (That my room was bright and that this interferes with seeing the relatively weak glow did not occur to me at this time.) Further, I did not notice that the lamp glow on one particular side that depends on the nature of the materials tested. Rather, I simply noticed glowing. When Manuela [Welzel] talked about it lighting on the other side, I actually turned the bulb around. I also attempted to touch the pants where I had prepared the [transparency] sheet. [E01p2]

The analysis of my own experience showed that the towers, for example, became perceptually salient when I passed them for the seventh time. At this time, the immanent nature of the towers turned into a transcendental fact. It is only at this point that I asked, "How could I not see these towers during my previous trips?" If I forget that the towers changed from being immanent to being transcendental in nature, I may react in the way my colleagues did observing physics students “who do not see the obvious.” That is, there is an “amnesis” (loss of the story) of the origins of perception.[3]

Even if these students visually tracked the filament, metal ends, or location of the glowing, it was not experienced as a bit of information. Just as in the example of the tear in my tire, it would have been (if in fact students had the impression) a difference that did not make a difference. The glow lamp was articulated—perceptually and in sentential form—as students attempted to find out why it “did not work.” That is, a breakdown gave rise to an attentional disposition prerequisite for the articulation of the perceptual field, that is, for the emergence of figure/ground distinctions that may have salience to the problem. Breakdown appears to disposition us to seek and notice things not immediately evident. The fact that things do not work (cannot be used) is discovered “not by looking and ascertaining properties, but rather by paying attention to the associations in which we use it” (Heidegger, 1996, p. 68). When a student such as Brita “discovered” a particular property of the lamp, it was because of a need that arose from her inquiry. Brita did not get her experiment to work. She had used different materials for rubbing but had not been able to get the lamp to light up. At one point she glanced at the bulb intently; it was at that point that the gap between the two electrodes emerged, became noticeable as a fact to be articulated. She saw the gap for a first time, although she had been looking at it repeatedly. The bulb was there, present to hand as something that glows or does not glow, but its internal structure was unavailable to her. With the gap, an association emerged with the lack of success in getting the experiment to work.

Was it that Brita expected the wire to be continuous, such as in regular light bulbs? She perceived the gap, the particular feature of this lamp, perhaps in its difference to other lamps that she is familiar with. Now, rather than treating the lamp as an undifferentiated whole (as she had done before) the association of filament gap and experimental failure suggested the possibility of a causal relationship that would explain the failure. Here then, the bulb is no longer mere equipment, but once it has become figure as something broken, its internal structure came to be conspicuous. The space between the two filaments came to protrude, forced itself into conscious awareness, raising the possibility of broken equipment.

3.3. Perceiving Graphical Features and Photoreceptors

In the two previous case studies, I showed that perception is a process of learning in which an initially indeterminate perceptual field is articulated to contain

[3] I chose “amnesis” because it is both the opposite of anamnesis (remembering) and a process; amnesia is a state, a product.

an increasing number of objects that stand out as figure against the indeterminate ground. In a scientific laboratory, too, perception is a process of learning how things are from the way they look, which requires extended exploration. In a laboratory where scientists collaboratively analyze visual displays, what is there to be see may differ between individuals (Amann & Knorr-Cetina, 1990). When such differences become evident (which is not always the case even during extended collaboration), the collaborators (usually) engage in efforts to assist others in seeing what they see. At the same time, because of an operating assumption that there is but one material world, these differences function as a sort of breakdown that needs to be understood and cleared up. The collaborators articulate what they see, and may use a variety of tools to assist in perception. Out of this process, collaborators come to perceive problematic situations in common ways. Over time, such situations of "breakdown" diminish because the perceptions have been adjusted and tools are no longer necessary to assist in seeing what there is to see. Individual perception is the outcome of a historical process and the internalization of (initially) externally mediated processes.

3.3.1. Context of Episodes

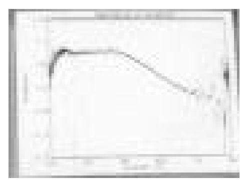
In this laboratory, the absorption of light in salmonid photoreceptors is measured. Usually, two individuals participate in the acquisition of data. One person makes the preparation, searches for the cells under the microscope, and lines up the image for scan (beam goes through cell) and reference (beam traverses preparation where there are no cells). The other individual operates, from the computer, the opening and closing of the shutter, online data transformation for preliminary analysis, and saving of data. The custom software calculates the absorption spectrum from the difference between scan and reference. There are different means by which the data plots can be manipulated, including changing the scales and lopping off left and right ends of the spectrum. Additional manipulation tools are made necessary because scan and reference a slight shift along the wavelength scale with reference to one another, the software feature "pixel shifting" allows to correct for presumed shifts. There is also the possibility for artifacts that show up as the superposition of a linear curve. "Detrending" is a process by means of which the researchers can eliminate the presumed trend. Finally, reference graphs based on previously published data can be calculated and superimposed over the actual data.

In the first episode, Greg operated the microscope and, peering through the ocular, attempted to identify cone-shaped retinal cells, which he then lined up for measuring the absorption spectrum. Later in the research (e.g., second episode), the microscopic image of the photoreceptor was displayed on the monitor so that the photoreceptor under investigation was perceptually available to all laboratory members. Tony operated the data collection through a computer interface, which also allowed him to manipulate the graphs that were produced. In the first episode, the equipment was arranged such that Greg had to turn his head/body about 70° to the left to see the monitor; he was the only one to see the slide (through the ocular).

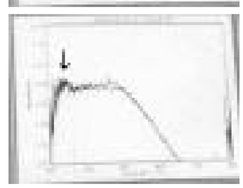
3.3.2. Episodes

Episode 1. The present episode contains an entire "run," during which the data were collected for the absorption spectrum of one photoreceptor. The nature of the cell and suitability of the corresponding absorption spectrum (graph) as scientific evidence are under debate. Both assessments rely on perceptual processes. The episode begins when Greg requested opening the shutter for scanning the photoreceptor identified and lined up under the microscope (reference spectrum had already been collected).

01 G: Scan (pause) Looks like a single cone.
02 T: It's very wide, that's the first problem.
(*continues transforming*)



03 This one right here (*points with cursor*)?
04 G: Too short?
05 M: About 3-40
06 G: Yeah, too short.



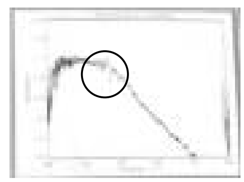
07 T: Yeah, too short.
08 G: See where I am here. (*Looks through*
09 *microscope.*) Off!
10 T: Off, Right.

Greg articulated the entity that he was gazing at through the microscope as a single cone (line 01), which implies that the cell should absorb light in the blue or UV part of the spectrum. Tony, gazing at the graph on the monitor described it as "too wide," then directed attention toward a small peak near the left of the spectrum. "Too wide" is critical because it cast doubt on what Greg had perceived. That is, it raised doubt on how things *really* are although they looked to Greg like a "single cell." Using the cursor, Tony then pointed to another perceptual feature; both assessed it as "too short" to be of interest. Greg then took another look and ascertained that the photoreceptor under the microscope "looks like a single cone."

11 G: Scan… Definitely looks like a single cone.

12 M: Hmm?

13 T: It's rather high, in the four-sixty again.

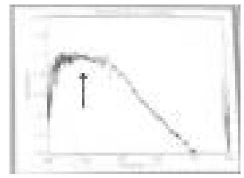


14 M: Yeah.

Tony and I noted "something" around 460 nanometers in the graph. That is, as we gazed at the graph, we both perceived the feature (of interest) at 460 nanometers whereas other features, such as the slope on the right hand side of the curve, or the features on the left hand side of the curve remained unmarked and, perhaps, unremarkable. However, by describing the four-ssixty feature as "too high," the utterances cast doubt on the object under the microscope. This doubt was of particular salience as, in other situations, Greg revised his assessment from "single cone" to "double cone," with corresponding graphical features in the green (around 460 nanometers) and red (around 600 nanometers) parts of the visible spectrum. That is, in those situations Greg learned how to better correlate how things are and the way they look (under microscope).

The next utterance made clear that something different was perceptually salient to Greg, to which he drew attention by pointing to it with his finger (arrow, lines 15–16). Again, there was a difference in perceptual salience, in what the different laboratory members perceive on the display. The group then explored one of these features and, by drawing on a variety of tools, increased its salience and thereby engaged in learning how things are (clear signal of photoreceptor presence) from how they look (almost invisible wiggle on curve).

15 G: Well, do a pixel shift, because I think
16 that one (*points to display [arrow]*) is
the peak.

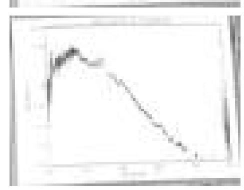


17 G: Again.

18 T: That doesn't look like it.

19 G: No, in the other direction
20 T: Yeah

21 M: This one?



22 G: May be one more. No, the other way. So
23 two that way.

24 OK. Now, detrend it.

As Tony performed the “pixel shifts,” which changed the perceptual field, Tony noted that he did not perceive something of interest (“that doesn’t look like it”). Greg instructed Tony to do a pixel shift “in the other direction, which entailed, for me, the emergence of some feature, which I referred to as “this one?” (line 21). In the next turn, Greg did not respond directly but noted that “maybe one more” was needed, before instructing Tony to “detrend it.” With this instruction, Greg ended giving pixel-shifting commands, an indication that the feature he perceived has been brought out as much this could be done. Readers can easily ascertain that there are at least two peak-like features that are currently visible. As Tony begins to “detrend,” Greg instructs him to continue with the process (line).

25 G: Yap. Keep on detrending.

26 OK, well, this one can go on forever.
27 (*Tony keeps on “detrending”*)
28 But, put a 3-80 up to see what it looks like.

29 T: Yeah. (*works on getting 3-80, seeking*
30 *flashlight*) It does fit under three-eighty.
31 G: There you go. Three-eighty?

32 T: Yep.

After a number of detrending moves, Greg (impatiently) instructed Tony to “put a three-eighty up.” In response, Tony plotted a standard graph (using previously published parameters) with a maximum at 380 nanometers over the meas-

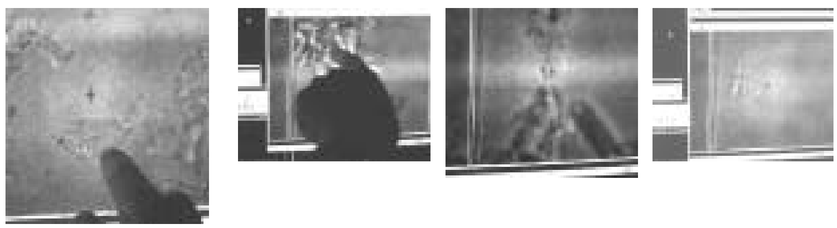


Figure 3. a. Telling the object. b. Indirectly referring to an object. c. Initial identification of a perceptual gestalt. d. Moving on without a comment 'tells' that the object is not a cone.

ured curve. He immediately ascertained that the curve ("it") fit the reference curve (lines 30–31). Greg sought confirmation that the reference curve indeed had a maximum at the earlier announced location. In this episode, the display initially offered different perceptual salience to Greg and Tony. Using the available tools, the perceptual salience of the peak at 380 nanometers was increased. Because this peak was consistent with the assessment "looks like a single cone," the data were retained. Now, more than one year later, both scientists do no longer need the tools to enhance the perceptual salience of a graphical feature. They know how things are from the way they look.

Episode 2. When I first joined the laboratory, I did not distinguish the research-relevant entities (rods, single cones, and double cones) from other materials in the visual field of the microscope. There were many shades of grey, lines and areas; but it was not evident what I was to take as salient figure and what was merely ground. To assist me in discriminating the objects of interest, Greg and Tony pointed to and articulated for me the relevant objects uttering "double cone," "single cone," "rod," or "epithelium" (Figure 3.a, b). Later, I began to ask question about the nature of the entity or stated a classification hypothesis (Figure 3.c). Through this feedback from the others in the laboratory, I came (over time) to perceive and articulate the field in a way that the appropriate perceptual gestalts were salient. I now distinguish what is a single cone from what only looks like a single cone (a broken rod or a double cone on its side).

Now, after having spent more than a year in this laboratory, I no longer need to be told—none of the lab members tells the object as they had done in the beginning. Lab members no longer point to or describe the entities (Figure 3.d). In fact, it would be seen as odd behaviour if I asked what there was to be seen; I am expected to see and instantly know. That is, everyone perceives what is there to perceive and, in the absence of comments to the contrary, knows the others to perceive in the same way. When the image continues to change as the microscope operator scans the slide, the laboratory members present "know" that the operator has not only continued to scan but also that he perceived the object as a specific entity (e.g., "rod" in Figure 3.d). Continuing in the search for appropriate photoreceptors does not only change the perceptual field but also tells others that some entity is not of interest. More so, (initiate) lab members know what is going on and what the operator has perceived, and they know that the operator knows the same about them. In turn, the silence of other members present "tells" the operator that they are in agreement with his assessment. That is, the absence of utterances and gestures communicates to the members of the laboratory what is going on and what others are attuned to.

3.3.3. Discussion

The data in these two episodes show that "perception" is neither straightforward nor self-evident. First, the entity that Greg identified under the microscope was questioned and thereby his perception—there was a strong possibility that what looked like a single cone in fact was something else. Second, the same graphical display was perceived differently within the group (lines 13–14 vs. lines 15–16)—these differences constitute a sort of breakdown that has to be actively explored. Third, several technologies are used in the exploration to aid perception at this stage of the research (detrending, pixel shifting, and layering of reference graph), allowing the researchers to correlate how things are (convergent information from photoreceptor image and graph) and how they look like (under microscope). Nowadays, the scientists no longer require the same technologies; they unambiguously identify both the visual displays (nature of the cell as single cone, double cone, broken rod) and the graphs. Fourth, even at this stage, seemingly similar displays were perceptually differentiated (line 03 vs. line 13); more so, the graph that appeared to show a clear feature was discarded while the other (contested) one was retained.

The perceptual phenomena in this third case study share structural features with the earlier case studies. During the early parts of the research, the scientists used a variety of tools to transform the graphs, which enhanced what was to become a figure. They actively manipulate the display, which changes the perceptual ground and enhances what is figure against the remaining ground. Later in the research, however, these tools were no longer necessary; scientists have become so attuned that they see the figure even if it is barely visible against the ground or occluded by other figures (or that part of ground that scientists call "noise."). Aspects of the absorption graphs that fore some time were part of the indeterminate (noisy) ground became figure against a receding ground that continues to be indeterminate. That is, perception does not instantly provide a pregiven world but arises historically, in the course of extended engagement with a particular segment of the world. Coming to see is a way of learning how the world is from one's immediate apprehension of features of how the world in fact is. This process which begins at birth, is indefinite and open-ended, making "vision […] a continuous birth" (Merleau-Ponty, 1964, p. 32). The historical nature of perceptual processes in the scientific laboratory is further highlighted in my own, documented changes in perception over the course of participating in the research. The perceptual processes that allow the distinction of (broken) rods, single cells, and double cones on the side from all other shades and lines (visible through the ocular objective [episode 1] or on the monitor [Figure 3]) were historically emergent features. These changes parallel those that I observed Greg and Tony to undergo, who no longer take a double cone on its side or a broken rod for a single cone. Through exploration of how the entities looked like, the perceptual fields became structured into recurrent figure/ground distinctions. Although some feature (figure), in a transcendental attribution, was said to have existed all along, it was only when it became a transcendent part of the scientist's lifeworld that the features had behavioral (and therefore scientific) significance.

4. TOWARD A PROPER APPRECIATION OF PERCEPTION

In this study, I articulated six important aspects of perception. First, perception of a particular segment of the world is indeterminate. Second, as individuals actively explore the relevant segment, their perceptual fields become articulated into figure/ground relations that give rise to more specific objects, themselves subject to future (verbal) articulation into figure and ground (whole/parts). Perception is a historical, experientially conditioned process making available different worlds rather than a transparent window on a stable world. Third, although we are visually attuned to our surroundings, we only see when something that we track becomes behaviorally relevant, that is, when this something is integrated with our capacities for thought and action-guidance. Fourth, articulation of the perceptual field and behavioral relevance often emerge in moments of breakdown. Fifth, in collective laboratory activity, contradictory observations have the function of, and solicit the same processes as (equipmental) breakdown. Sixth, when some feature emerges into awareness for the first time, it immediately changes its nature from something that was only immanently present to something that is transcendentally present. Perceptual amnesis is the process by means of which we forget that the world given to us in conscious perception is the result of a learning process. This study used phenomenological methods, designed to deal with normally inaccessible presuppositions, to recover what we generally do not see because of the process of amnesis. These findings stand in contrast to many current assumptions, (developmental and cognitive) theories, and (educational) practices. My study therefore has far-reaching consequences for educational theory and praxis. Here I focus on two salient issues: (a) the relationship between perception, learning, and development; and (b) the practical consequences that arise from this for (science) education.

4.1. Perception, Learning, and Development

This study showed that the world as it appears to individuals is under continuous change; our lifeworlds, the worlds we perceive and towards which we act are under continuous transformation. We continuously see new things even in familiar surroundings and get better at seeing how things are from the way they look. These observations fly into the face of the assumptions underlying educational theory and practice. As science teachers, do we not assume that students see relevant events in a demonstration? As mathematics teachers, do we not assume that students see a collection of cuisinaire rods in a particular way? As theorists, do we not assume that children interact with (the structures in) a stable world that is, through experience, assimilated into an appropriately adapting (accommodating), autopoietic mind? As the following example shows, there exists some research that supports the present findings.

Piaget and his followers described the development of reasoning on the balance beam (Case, 1985; Inhelder & Piaget, 1958) in terms of the progressive evaluation of weight and distance. Whereas the child initially focuses on weight or distance only, it will (in the concrete operational stage) develop and use an addition schema to make judgements about the behavior of a lever given the weights and distances on either side. The child begins (in the formal operational stage) to relate weights and distances by means of the proportionality scheme. In this approach, it is assumed that children perceive weight and distance in the way adults or scientists take these features. In fact, for Piaget’s theory to work one has to assume that children perceive the world measured and explained by scientists (Meyer-Drawe, 1986). Recent research raises serious doubts about the sequence of events (Metz, 1993; Roth, 1998). The preschool and seventh-grade children in the Metz and Roth studies did not at all act upon the properties of weight and distance. Rather, these properties were the *outcome* of extended perceptual and motor experiences with the materials at hand. For example, the seventh-grade students initially attended to the *position* of the weights along the beam followed by attention to *change of location*, *size of change in location*, and *relative distance*. Only when the relative distance was indexed to the fulcrum did these students perceptually attend to "distance" as conceived in the developmental literature. That is, the children did not perceive and act in a world as Piaget and others understood; rather, the perception of this world in these terms was the *outcome* of interactions of a behavioral environment perceived in very different ways. The world available to these children had changed as my world had changed with appearance of the towers, or the "Landwehr" and kilometer signs, and as it had changed for the tenth-grade physics students when an increasing number of features characterized their glow lamps. There was furthermore a progression from what appeared to be the case on the balance beam and what they subsequently knew as how things really are—similar to the progressive perceptual competence in seeing graphical features and single cones on the part of the members in the scientific laboratory.

The results of this study suggest that we ought to take individuals' perceptions and their perceptually available worlds as changing. Such an approach offers a genealogy of experience, crises, and regressions that are not orientated primarily toward the development of a scientific rationality. It offers a lived reorientation of the field of experience that includes the perceptive field and its changes in a constitutive way. This allows us to emphasize the poietic character of concrete sensorimotor actions that are always situated in and always transform the embedding situation. The developing individual (student or scientist) is imbued with its own rationality; this rationality is not to be measured using a known developmental endpoint as teleological referent. We can then see development as a double reorganization including both the assimilation of things in the world we perceive and the transformation of the (perceptual) object world. We do not encounter an autonomous, monothetic world, characterized by object permanence and invariant structures. Rather, the very world encountered by the developing individual is a function of the genealogy of its experience. If our (educators, educational psychologists) aim is to understand development, we need to understand what the individual perceives, which is to be thought of as an order that is neither chaotic nor rational in the Western scientific sense of the word.

4.2. Educational Practice

The theoretical perspective on the relationship between perception and development has profound implications for education. For example, science demonstrations and science museums are based on the (implicit) assumption that perception extracts something from visual stimuli (by looking, starring, observing, etc.) that supports understanding scientific discourse. Likewise, the use of hands-on activities is based on the (implicit) assumption that students can extract something from their perceptual experience that leads to or supports the development of abstract scientific knowledge. How this is supposed to happen is seldom if ever discussed in the literature on learning from hands-on activities. If lifeworlds (and its objects) are brought forth through active exploration and if perception differs then we need to begin research on cognition by investigating what students actually rather than what they possibly or ought to perceive. Students react to and change because of the things *they* perceive, which they integrate in their thoughts and action-guidance, rather than because of the things that researchers, teachers, or physicists perceive. I suggested that as teachers we often forget that our worlds are not pre-given but that what is perceptually available to us had, at one point, emerged into our conscious thoughts during exploration. This amnesis impedes the understanding of students' difficulties in learning from a simple observation such as this occurs in demonstrations.

We can assume that students' perceptions (in laboratory activities, demonstrations) provide them with a fundamental experience; they orient what they do and think to what they perceive as real. But, looking at something once or twice usually does not allow students see—that is, to know how things are from how things look. This form of perceiving requires extended exploration. Yet, to provide another example, many textbooks provide just one photograph to illustrate a concept. Clearly, one sample image is insufficient for learning to make a perceptual distinction between instances and non-instances of a concept.

A phenomenology of perception is therefore basic to all further reflection on the relation between conscious observers and their worlds (Schuhmann & Smith, 1985). However, the present investigation shows that we have no conscious control over what is perceptually revealed next. We do not construct our perception or observations; this image of someone constructing perceptions and knowledge is akin to the Cartesian homunculus extracting information from the screen. New objects and events are thrust into my awareness and therefore become furniture of my lifeworld. At best, then, we can prepare for perceiving in new ways by putting ourselves into a state of readiness, allowing ourselves to be open toward disclosure of the unknown. (This is the same disposition required of the researcher, who attempts to make sense of videotapes, transcripts, or interviews. It is through extended exploration of our materials [databases] that we come to see new entities and processes.)

The value of conscious reflection in the evolution of perception does not lie in some capacity to overcome perception but rather in its capacity to remain faithful to the sensorial sources from which it sprang. It is when the things we perceptually track become salient and integrated into our capacities for thought and action-guidance that we change from merely looking at to *seeing*. To become salient at all, an event or process (to be discriminated as this or that event within a dynamic situation as a whole) must have underlying invariant structure of properties that does not change in the course of exploration (Smith & Casati, 1994). Perception presupposes and includes as an inextricable feature the exploration of the world. These invariants are hierarchically organized and concern the whole or part of the event; that is, some elements are suppressed others are essential.

5. CODA

This study showed that to perceive is, in some ways, to encounter things and to give sense to the world by actively exploring and orienting within it. Perception is a changing process that continually constitutes new objects and events. Each time we perceive something new, we also reconstitute our worlds by taking what is salient and giving it meaning. The findings reported in this study have considerable implications for research and praxis. If the developing individuals always and already act in and toward a subjective world, we have to ask, How is it possible that they eventually come to by-and-large agree on perceiving the world in the same way? (There are exceptions, which are treated under such labels as schizophrenia, hallucinations, etc.) How is it possible that some individuals become scientists, learn to perceive the world in a particular way, although their early perceptions are rather distinct from those of scientists? Thus, how do individuals become scientists when they cannot derive structures by interacting with a fixed world? There is a field rife of interesting research questions for educational and psychological investigations. I caution researchers, however, to describe the developmental changes as they occur in response to a polythetic world (perceived by different individuals) rather than in response to a monothetic (uniquely structured) world.

ACKNOWLEDGMENTS

This study was supported in part by Grants 410-99-0021 and 412-99-1007 from the Social Sciences and Humanities Research Council of Canada and by a fellowship in the cognitive neurosciences by the Hanse Institute of Advanced Studies, Delmenhorst, Germany. I am grateful to Manuela Welzel, who provided me with access to the database in the tenth-grade physics class that she had taught, and for serving in the capacity as disinterested peer. My gratitude also extends to Craig Hawryshyn and Theodore Haimberger who allowed me into their laboratory and who taught me so much about fish vision and how to analyze it.

REFERENCES

Agre, P. E. (1997). *Computation and human experience*. Cambridge: Cambridge University Press.

Amann, K., & Knorr-Cetina, K. D. (1990). The fixation of (visual) evidence. In M. Lynch & S. Woolgar (Eds.), *Representation in scientific practice* (pp. 85–121). Cambridge, MA: MIT Press.

Anderson, J. R. (1985). *Cognitive psychology and its implications*. San Francisco, CA: Freeman.

Bateson, G. (1972). *Steps to an ecology of mind*. New York: Ballantine.

Case, R. (1985). *Intellectual development: Birth to adulthood*. Orlando, FL: Academic Press.

Churchland, P. M. (1995). *The engine of reasoning, the seat of the soul: A philosophical journey into the brain*. Cambridge, Mass: MIT Press.

Churchland, P. S., & Sejnowski, T. J. (1992). *The computational brain*. Cambridge, Mass: MIT Press.

Clancey, W. J. (1997). *Situated cognition: On human knowledge and computer representation*. Cambridge: Cambridge University Press.

Decety, J., & Grèzes, J. (1999). Neural mechanisms subserving the perception of human actions. *Trends in Cognitive Sciences*, *3*, 172–178.

Depraz, N., Varela, F., & Vermersch, P. (2000). The gesture of awareness: An account of its structural dynamics. In M. Velmans (Ed.), *Investigating phenomenal consciousness*. Amsterdam: Benjamin Publishers.

Edgerton, S. (1985). The renaissance development of the scientific illustration. In J. Shirley & D. Hoeniger (Eds.), *Science and the arts in the renaissance* (pp. 168–197). Washington, DC: Folger Shakespeare Library.

Guba, E., & Lincoln, Y. (1989). *Fourth generation evaluation*. Beverly Hills, CA: Sage.

Heidegger, M. (1996). *Being and time*. (Transl. J. Stambaugh). Albany: State University of New York Press.

Holzkamp, K. (1991). Experience of self and scientific objectivity. In C. W. Tolman & W. Maiers (Eds.), *Critical psychology: Contributions to an historical science of the subject* (pp. 65–80). Cambridge: Cambridge University Press.

Hut, P. (1999). Exploring actuality through experiment and experience. In S. R. Hameroff, A. W. Kaszniak, & D. J. Chalmers (eds.), *Toward a science of consciousness III* (pp. 391–405). Cambridge, Mass.: MIT Press.

Il'enkov, E. (1982). *Dialectics of the abstract and the concrete in Marx's Capital* (Transl. Sergei Kuzyakov). Moskow: Progress.

Inhelder, B., & Piaget, J. (1958). *The growth of logical thinking from childhood to adolescence*. New York: Basic.

Jarvilehto, T. (1999). The theory of the organism-environment system: III. Role of efferent influences on receptors in the formation of knowledge. *Integrative Physiological and Behavioral Science, 34,* 90–100.

Merleau-Ponty, M. (1945). *Phénoménologie de la perception*. Paris: Gallimard.

Merleau-Ponty, M. (1964). *L'œil et l'esprit*. Paris: Gallimard.

Metz, K. E. (1993). Preschoolers' developing knowledge of the pan balance: From new representation to transformed problem solving. *Cognition and Instruction*, *11*, 31–93.

Meyer-Drawe, K. (1986). Zähmung eines wilden Denkens? In A. Métraux & B. Waldenfels (Eds.), *Leibhaftige Vernunft: Spuren von Merleau-Pontys Denken* (pp. 258–275). Munich: Wilhelm Fink Verlag.

Noë, A. (in press-a). Is perspectival self-consciousness nonconceptual? The Philosophical Quarterly.

Nöe, A. (in press-b). On what we see. Pacific Philosophical Quaterly.

O'Regan, J. K. (2001, January). *Experience is not something we feel but something we do: a principled way of explaining sensory phenomenology, with change blindness and other empirical consequences*. Paper presented at the Nineteenth European Workshop on Cognitive Neuropsychology, Bressanone, Italy.

O'Regan, J. K., & Noë, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences*, *24* (5), xxx–xxx.

Pessoa, L., Thompson, E., & Noë, A. (1998). Finding out about filling in: A guide to perceptual completion for visual science and the philosophy of perception. *Behavioral and Brain Sciences , 21*, 723–802.

Petitot, J. (1994). Phenomenology of perception, qualitative physics and sheaf mereology. In R. Casati, B. Smith, & G. White (Eds.), *Philosophy and the cognitive sciences* (pp. 307–408). Vienna: Hölder-Pichler-Tempsky.

Quine, W. V. (1995). *From stimulus to science*. Cambridge, Mass: Harvard University Press.

Ricœur, P. (1991). *From text to action: Essays in hermeneutics, II*. Evanston, IL: Northwestern University Press.

Rizzolatti, G., Fadiga, L., Fogassi, L., & Gallese, V. (1997). The space around us. *Science*, *277*, 190–191.

Rorty, R. (1979). *Philosophy and the mirror of nature*. Princeton, NJ: Princeton University Press.

Roth, W.-M. (1998). Starting small and with uncertainty: Toward a neurocomputational account of knowing and learning in science. *International Journal of Science Education, 20*, 1089–1105.
Roth, W.-M., Bowen, G. M., & Masciotra, D. (2002). From thing to sign and 'natural object': Toward a genetic phenomenology of graph interpretation. *Science, Technology, & Human Values*, *26*.
Roth, W.-M., McRobbie, C., Lucas, K. B., & Boutonné, S. (1997). The local production of order in traditional science laboratories: A phenomenological analysis. *Learning and Instruction, 7*, 107–136.
Schuhmann, K., & Smith, B. (1985). Against idealism: Johannes Daubert vs. Husserl's Ideas I. *Review of Metaphysics, 39*, 763–793.
Smith, B., & Casati, R. (1994). Naïve physics: An essay in ontology. *Philosophical Psychology, 7*, 225–244.
Suzuki, D. (1989). *Inventing the future: Reflections on science, technology, and nature*. Toronto: Stoddart.
Tabachneck-Schijf, H. J. M., Leonardo, A. M., & Simon, H. A. (1997). CaMeRa: A computational model for multiple representations. *Cognitive Science, 21*, 305–350.
Varela, F. J. (1996). Neurophenomenology: A methodological remedy for the hard problem. *Journal of Consciousness Studies, 3*, 330–350.
Varela, F. J., & Depraz, N. (2000). At the source of time: Valance and the constitutional dynamics of affect. *Arob@se, 4* (1-2), 143–166.
Varela, F. J., & Shear, J. (1999). First-person methodologies: What, why, how? *Journal of Consciousness Studies, 6* (2-3), 1–14.
Varela, F. J., Thompson, E., & Rosch, E. (1993). *The embodied mind: Cognitive science and human experience*. Cambridge, MA: MIT Press.
von Uexküll, J. (1973). *Theoretische biologie* [Theoretical biology]. Frankfurt: Suhrkamp. (First published in 1928)
Wallis, G., & Bülthoff, H. (1999). Learning to recognize objects. *Trends in Cognitive Sciences, 3*, 22–31.
Welzel, M. (1995). Interaktionen und physiklernen: Empirische untersuchungen im physikunterricht der sekundarstufe 1 [Interactions and learning in physics: Empirical studies in lower secondary physics]. Frankfurt: Peter Lang.
Wittgenstein, L. (1975). *Philosophical remarks*. Chicago: University of Chicago Press.