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Chapter 10

LIMITS TO GENERAL EXPERTISE: A STUDY OF IN- AND OUT-OF-FIELD GRAPH INTERPRETATION

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ABSTRACT

Graphs are pervasive features in professional science journals, which makes graphing one of (if not the) most important practice (and therefore skill) of professional science. Scientists generally are expected to be experts in graphing. Contrary to this expectation, recent investigations showed that scientists asked to interpret graphs from introductory-level textbooks in their own field did not at all exhibit expert-like behavior. The present study was designed to understand better the nature of graphing practices among professional scientists. I investigated the similarities and differences in scientists' interpretation of structurally identical in-field and out-of-field graphs. Seventeen physicists interpreted 3 graphs that were derived from entry-level university textbooks in ecology—for cross validation purposes, these were the same graphs used in an earlier expert-expert study—and 3 structurally identical graphs from the field of physics. My analyses reveal that the graphing expertise of physicists is limited even within their field. Their graph interpretations are highly idiosyncratic and contingent both within and across content domains. Common to the interpretive practices on in-field and out-of field graph was that scientists interpreted them according to the purposes of (a) graphing in science in general and (b) those of the graph interpretation interview session specifically. In using varying resources and in experiencing breakdowns, they exhibited considerable differences between in-field and out-of-field graph interpretations. Working on in-field graphs, they drew on general knowledge and prior experiences from their professional life, whereas in the context of out-of-field graph interpretations, scientists provided verbal equivalents for the visible, surface features of the line graphs and drew on mundane everyday life experiences to explicate them.

INTRODUCTION

Research in the cognitive and learning sciences has tremendously increased our understanding of what it means to be an expert in a domain and how to acquire the characteristics of an expert. Although there are lively debates about how someone acquires the characteristics of an expert, the characteristics themselves largely remain undisputed. In much of the literature concerning expert-novice differences, scientists are shown to exhibit exemplary expertise in comparison with novices, for example, in problem solving, in using representations, in experimentation strategies, and in ecological sorting tasks (e.g., Shafto & Coley, 2003). Graphing is no exception (Larkin & Simon, 1987) and practicing chemists outperformed chemistry students on tasks requiring transformations of graphs into other representations or vice versa (Kozma & Russell, 1997). Because graphing is one of the central practices of professional science at work without which science as such would not exist (Latour, 1987), scientists are assumed to be *general* experts in many of graph-related studies of expertise (Tabachneck-Schijf, Leonardo, & Simon, 1997). But contrary to general expectations about scientists' graphing competencies, recent studies showed that scientists, too, experience difficulties in interpreting graphs, even when these have been culled from introductory, first-year undergraduate-level courses and textbooks in their own field (Roth & Bowen, 2001). Furthermore, statistically reliable differences between the success rates of university-based and public-sector scientists were detected, which led to the hypothesis that performance is due to familiarity rather than to special ability (Roth & Bowen, 2003). Thus, it was shown that eighth-grade students in a learning environment with great family resemblance to research in the natural sciences developed data analysis and representation skills that were significantly better than those of teacher candidates with bachelors and masters degrees in one of the natural sciences (Roth, 1996). It is improbable that scientists, successful in their careers (i.e., publication rates, grants, scholarships or awards), have cognitive deficiencies that lead to their trouble during graph interpretations. To understand and explain scientists' graph-related expertise requires a different method for analyzing how scientists know and learn mathematical representation, and therefore new approaches focus on graphing not as cognitive abilities but as social practice (e.g., Roth & McGinn, 1998). Perhaps more radically still, a cognitive anthropology of graphing focuses both on the cultural and phenomenological dimensions of expertise (Roth, 2003); and such a position has led to a better understanding of the problems scientists experienced in graph-related practices and competencies.

The research presented in this chapter was designed to investigate the nature of scientists' graph interpretation expertise with a special focus on the similarities and differences between in-field and out-of-field graph interpretation practices but keeping constant the affiliation that was a variable in a previous study where the sample consisted about half and half of university and public sector scientists (Roth & Bowen, 2003). In the present study, university-based physicists provided graph interpretations for (a) a set of three graphs from ecology that had been used in the earlier expert-expert study of graphing with ecologists and (b) three structurally equivalent graphs from introductory courses in their own field (physics). I use the same social practice perspective that informed the earlier study, which amalgamates the cultural and phenomenological perspectives, to understand and explain scientists' graphing expertise especially the limits of this expertise related to graphs issuing from both within and outside their domain.

Previous studies of scientists' graphing (e.g., Roth & Bowen, 2003) were mainly concerned with graphs within the scientific field of the expert participants. If graphing is a general expertise, then we would expect scientist to transfer their practices from one domain to another. In this study, I am concerned with the question of the extent to which graphing expertise goes beyond the boundary of a field. In the extension of existing studies to understand graphing expertise of scientists, the present one was designed to answer the question, "What are the similarities and differences in scientists' interpretation between in-field graph and out-of-field graph?"

BACKGROUND

Graphs and graphing are quintessential aspects of science; without them, science, as we know it today, would not exist (Edgerton, 1985). However, graphs were not used generally in scientific reporting until the XIXth century. In theoretical ecology, for example, the approach of modeling populations by means of graphs emerged as recently as the 1950s (Kingsland, 1995); in physics, although introduced in the 1920, entropy-temperature graphs still are not used widely in the teaching of the field, though such graphs have many advantages over others in modeling and making visible important aspects of thermodynamics (Roth, in press). In scientific and engineering communities, graphs have been used for three major purposes. First, graphs are material objects that constitute and represent other material but natural objects; existing anthropological and sociological studies have shown how the natural objects are translated through hierarchies of inscriptions until ultimately published (Latour, 1993). Second, graphs serve a rhetorical function in scientific communication. They are constructed such that the research results are difficult to question, and if such were the case, the critic would have to spend at least as much effort and resources into producing the critique as it took to produce the original result (Latour, 1987). Third, graphs act as conscription devices that mediate collective scientific activities, both bringing scientists together and constituting a joint focus for their ongoing talk that is conducted both *over* and *about* them (e.g., Ochs, Gonzales, & Jacoby, 1996).

In this study, I adopt a social psychological perspective, which ascertains that all higher cognitive functions are but traces of societal relations: any sign and its use are concretely available in and through participation in societally organized activity (Bakhtin, 1986; Vygotsky, 1986). In this perspective, the focus of research shifts from the analysis of mental structures to the structures of participation in the practices of communities of knowing. Graphs constitute signs and their use is objectively given in society; and any related higher-order mental function can therefore be studied sociologically (Vološinov/Bakhtin, 1973).[1] Graph interpretation practices always occur in social context in which the meanings of graphs

[1] As I make use of both the French and the English translations of this work, which sometimes differ in substantial ways, I am referencing both authors under which the French version has been published. There is some confusion about the extent to which Bakhtin contributed, although he is the author of the French version of the book. The English version is entirely attributed to Vološinov, though some Anglo-Saxon authors do attribute the book to Bakhtin as well.

are the outcome of negotiations within the collectivity; and interpretations reflect concrete (singularized) realizations of general possibilities for saying something about a graph. To analyze graph interpretation as a social practice, this conceptual framework needs a set of components including ongoing concerns, standard practices, material and linguistic resources, and sets of typical breakdowns (Bowen, Roth, & McGinn, 1999).

In this study I take a social psychological framework to analyze the physicists' graph interpretation practice. The standard graph-related practices in physics include such activities as designing experiments for the purpose of producing graphs, constructing graphs from the experimental data, writing articles in which graphs are used as evidence, and interpreting and critiquing graphs that other people produced. Sets of material resources in graphing include axis labels, units, and scales as well as mathematical and statistical software that allow the production and manipulation of graphs. Sets of linguistic resources in physics include mathematical formulas as another formal language to describe the same phenomenon as much as verbal language. Absence of appropriate tools or changing of familiar contexts can lead to breakdown, which is constituted by interruptions of standard practices and slow-downs in the progress of an activity.

RESEARCH DESIGN

This study was designed to better understand the activities in which physicists interpret in-field and out-of field graphs. By investigating the practices of their interpretation both in-field and out-of-field graphs, focusing on the similarities and differences, one might get at the general features of graphing competency and give some suggestions to the educators who want to teach their students the graphing competency in their teaching context.

Participants

A total of 21 (18 male, 3 female) physicists participated in this study, including two individuals who majored in applied mathematics but work in a physics-and-astronomy department. There were 15 professors, one postdoctoral fellow (1 year since PhD), and five PhD students (just graduated; 6 months, 9 months, 2 years, and 2 years from graduation). The professors had obtained their PhD degrees between 6 to 42 years prior to our interviews/think-aloud protocols (X = 23.25, SD = 14.1 years). All participants had a minimum six years of experience in doing independent research. All but one individual were involved in teaching graduate, undergraduate, or laboratory courses in physics and physics-related department such as astronomy, geophysics, ocean physics, and physical chemistry—thereby keeping constant the variable that led to differences in performance in the Roth and Bowen (2003) study. For purposes unrelated to the present study, four physicists worked in groups of two. The present study is concerned with the results from the remaining 17 individuals because the independent contributions of collaborating physicists could not be established from the transcripts. An undergraduate research assistant (pseudonym David), with a double major in physics and anthropology, conducted the interviews/think-aloud protocols with the physicists as part of a work term of the cooperative program in which he was enrolled.

For the purposes of the second part of this study, I draw on the interviews conducted with Annemarie, an associate professor in a department of physics and astronomy who had received her PhD more than 30 years prior to our study. She regularly published in academic journals and was acknowledged as an excellent teacher in the science faculty as evidenced by teaching awards. David attended a coop program. Seeking employment and being interested in anthropology, he was hired and trained specifically for eliciting graph interpretations from physicists pertaining to graphs from within and outside their field (i.e., ecology). In his program, he was near the median in terms of achievement. He liked the experience doing social science research so much that he first took courses in qualitative research methods and then changed his major to anthropology.

Tasks

In this study, six graphs, three from biology and three from physics were used to compare the interpretation of in-field and out-of-field graphs. The three biology graphs had been employed previously in studies with ecologists (Roth & Bowen, 2001, 2003). These graphs include a distribution, a population dynamics (model), and an isoclines graph typical of those found in introductory first- or second-year undergraduate textbooks in ecology, especially those texts that take a more theoretical perspective. The physics graphs were constructed by a similar method: they were selected and prepared from university-level physics textbooks such that they were (deep-structure) analogues of the biology graphs and were accompanied by a caption that was adapted to the physics content of the graph. (There were some slight surface variations due to the available textbook materials: for example, the biology population graph does not have units on the abscissa, whereas the physics graph has an abscissa label that has concrete numbers on both end of its axis.) For the analogies to be correct, both the structure of the phenomena and their representation had to be similar. Possible graph candidates were photocopied and the appropriate captions were added.

One set of graphs used in the present study featured two curves with “forces” that affect some phenomenon. In the out-of-field case, the task displays birthrate and death rate as functions of population size (density); the two curves intersect twice (Figure 1a). As inscription, the graph constitutes a model of the type that ecologists began using during the 1950s and 1960s (Kingsland, 1995). Birthrate and death rate constitute opposite forces on the population size. A population is in equilibrium when the two forces are equal. The in-field equivalent from physics was created using a mathematical software package based on a dynamical system from classical mechanics (Figure 1b). The graph constitutes the model of a two-dimensional pendulum bob moving above two magnets. There are therefore two forces acting on the bob, one to the left, and the other to the right depending on the bob’s relation with respect to the magnet (magnetic force) and its position with respect to the lowest point of its trajectory (gravitational force). In this pair of tasks, participants were specifically asked to focus on the two intersections of the opposing forces (rates) and the resulting three sections along the abscissa. The correct interpretation identifies the two intersections as an unstable and a stable equilibrium, respectively. Such graphs can be found, for example, in introductory courses dealing with atomic physics, where there are repulsive and attractive electrical forces acting between two atoms. Thus, for example, the Lennard-Jones potential results from two forces, an attractive force at long ranges (van der Waals force) and a repulsive force that derives from the overlap of electron orbitals (based on the Pauli exclusion principle).

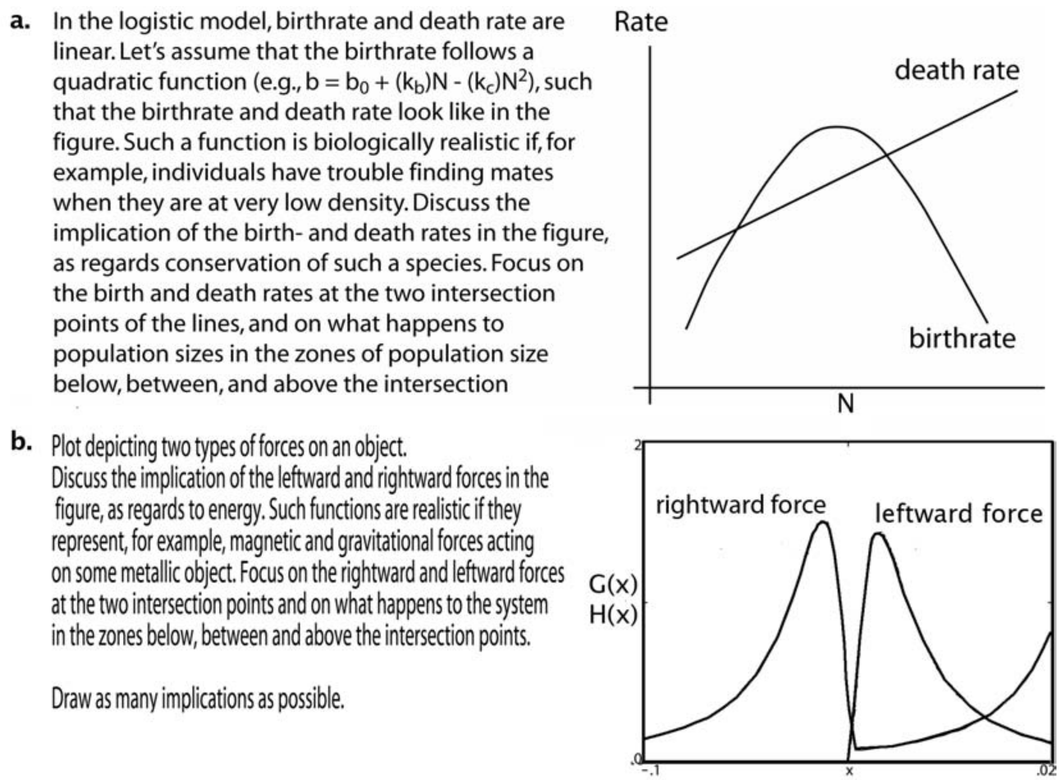

Figure 1. One of the three pairs of graphing tasks featuring an out-of-field and an in-field graph. a. Graph culled from an ecology textbook for teaching stable and unstable equilibrium. b. Graph produced using a mathematical modeling program using a real two-dimensional magnetic pendulum in the Earth's gravitational field.

The second set of graphs featured distributions taken from textbooks in ecology and quantum mechanics, respectively. Whereas in the biology distribution graph, three different types of plant distribution have to be used to make inferences about the differential adaptations to environmental conditions, in the physics distribution graph the different distribution of electron charges in consecutive four s-shells are used to make inferences about the differential ionization energies for each shell (K, L, M, . . .). The caption attached to each graph provided the participants with the associated situation. Thus, in the ecology graph, the participants weer informed about the actual study in South Texas that had led to the publication of the results in a journal, from where it was taken and adapted for didactic purposes in textbooks and ecology courses. The task instructs participants to think aloud about the implications that could be drawn from the graph.

The third set of graphs features the interaction of two variables in their effect on a third variable represented in the form of isoclines (lines of equal effect). The three biology isocline graphs represent *essential*, *substitutable*, and *complementary* resources, respectively. The three physics isoclines graphs represent a compressible-gas-to-liquid phase transition, ideal gas, and incompressible-gas-to-solid phase transition. The physics graph was created using a graphics package to produce a contour plot and was representative of thermodynamics graphs in our collection of physics textbooks featuring the interaction of pressure and volume of a substance at various temperatures.

Collection of Data Sources

The physicists were asked to participate in a graph interpretation session for the purpose of providing expert answers to the selected graphs. Participants were given the following instructions: "Make as many inferences as possible for each of the graphs. Think aloud. If you read text that appears on the page, read it aloud. We are interested in what is going through your mind as you are trying to tell us what you infer." Prior to the graphing sessions, a brief structured interview was conducted to establish biographical background information. All physicists were asked a standard set of questions to find out about the physicist's background. These questions included the time since PhD, how many postdoctoral years they did, how many years they have held a faculty position, the specialty area in which they conduct research, the courses they have typically taught, and the approximate per annum rate of peer-reviewed journal articles they published.

When participants stopped talking during a session, the research assistant was instructed to remind them to talk aloud by asking them to "say what you are thinking right now." (This was not always the case, as shown in the second part of the findings presented here.) The research assistant also tried to avoid answering questions as much as possible, because it was essential to get as much data as possible directly from the participants. (The transcripts provided below both provide evidence for his resistance to respond to queries about the correctness of interpretations and the continued nature of queries from the participants.) Once the physicists stopped interpreting but had not addressed certain salient issues, I had prepared a standard set of pre-formed questions and prompters for the physicists so they would continue to interpret those aspects of the graphs not yet talked about. For example, few physicists addressed the question about where along the abscissa (i.e., for which "N") the increase in the population was largest in the population graph; in these cases, the research assistant asked where the increase in terms of the absolute number of individuals in the population was largest. The participants were instructed to indicate when they had nothing more to say and therefore when they considered being done. In this case, the research assistant asked participants to turn to the next graph. The sessions including all six graph interpretations lasted between 30 and 100 minutes.

Data Sources

To begin with, all interviews were completely transcribed verbatim and, where necessary, video offprints coded according to their temporal position on the tape were inserted into the transcript to show gestures toward particular aspects of the graphs. In a second pass, the VHS videotapes were digitized (Macintosh iMovie); offprint images capturing characteristic moments were created from this software and imported into the transcripts. From all the transcribed interviews, one was randomly selected for close analysis in this chapter. For salient and theoretically interesting episodes, the transcription was improved to contain multiple video images, the length of the pauses, or the overlap between speech and gestures. In a second moment of analysis, theoretically interesting episodes and entire sessions were digitized and transcribed to include pauses longer than 0.10 seconds, overlapping speech with the interviewer, change in stress and loudness, and so forth (accuracy better than ±10 milliseconds). At a third level of analysis, the entire sound track of the interview was graphically represented in terms of waveform, speech intensity, and pitch using PRAAT (http://www.fon.hum.uva.nl/praat/), a freely available, cross-platform (PC, Macintosh, UNIX) software package for linguistic analyses. Information on these speech parameters were extracted directly from the displays, which were also saved using the relevant software features.

Using Peak™ DV 3.21, which allows the graphical representation of the waveform, pauses in and overlaps of speech were determined and entered into the transcript; this program was also used to coordinate utterances with the video offprints of the situation. Individual utterances were timed with an accuracy of ±0.001 seconds but rounded to the nearest 10 milliseconds and coordinated with the frames that allowed timing to 33 milliseconds (30 frames/second rate of the VHS video). The sound track was then analyzed for loudness (volume), intensity, and pitch. The complete output of PRAAT was checked and, where it was problematic, pitch was determined manually from the waveform.

Data Analyses

The present analyses are based on the assumption that reasoning is made observable by interaction participants in and as practical, socially structured, and embodied activity (Garfinkel, 1967). For example, by uttering, “Oh, it *says* a function of population,” Annemarie made available to David surprise and discovery: she declares a form of realization, which we might gloss as, “Oh, until now I have not attended to the fact the text states that birthrate and death rate are functions of population.” In this way, interaction participants continuously made available for one another actions and reasons for why they do what they do. The analyst does not have to assume any evaluation of Annemarie’s state of knowledge. Rather it is how she displayed her putative interpretation as a resource in the ongoing analysis of the graphical material that is significant. In other words, the-topic-of-interpretation is used as resource-for-interpretation. The videotapes, transcripts, and artifacts produced by the observed individuals therefore are natural protocols of the participants’ efforts in communicatively establishing their mutual sense that they made of the task at hand—consisting of both interpreting the graph and making the think-aloud/interview situation happen in a recognizable and scientifically acceptable way. These protocols constituted the materials that were structured, elaborated, and theorized in this study.

This ethnomethodologically informed approach also requires that “the analyst be, with others, in a concerted competence of methods with which to recognize, follow, display, describe, etc., phenomena of order* in local productions of coherent detail” (Garfinkel, 2002, p. 176). As the experience during data analysis showed, it turned out to be an advantage that the author, too, had obtained a graduate degree in physics. For example, when I analyzed the data with a social psychologist colleague (D. Middleton) he differed in the interpretation of the following utterance, in which the research assistant first described a procedure in terms of the subtraction of death from birthrate, then stopped, and re-articulated the procedure in terms of an addition of birthrate and death rate, where the second term is negative. The first way of relating birthrate and death rate for finding the overall rate of change (b – d) is typical in the community of biologists, from which the graphing task was taken, and which is implied in the positive values the death rate takes in the task (Figure 1). (For the transcription conventions used, see the appendix.)

Fragment 1

```
040  D:   well, yeah, if you take, well shall i think i use the half if
          you take the birth minus the death (.) rate (0.63) `well the
          birth plus the death which is negative, you are gonna get
          (0.13) some positive (0.98) growth rate; right?=
```

Physicists, on the other hand, typically sign negative those rates that decrease the quantity at hand but add the constitutive rates, here this would be b + d where d would be a negative quantity. A correct interpretation—the research assistant David exhibiting knowledge typical of a physicist rather than a biologist—requires familiarity with the practices of physics. My colleague, a social psychologist unfamiliar with the practices within the physics community—or the ecology community that I have studied ethnographically for more than a decade—provided interpretations that were not grounded in and consistent with the standard practices of the field. Once my colleague and I took this knowledge into account, we came to a shared interpretation (provided below).

Following the precepts of interaction analysis (Jordan & Henderson, 1995), I began by taking my data sources to collective analysis sessions, which last about three hours each, and where all the members of my laboratory contribute to working through the tapes in a second-by-second manner. Our collective analysis proceeds in the following way. The researcher at the controls—here this was me—runs the video until someone requested to stop to talk about a feature or episode—usually the episodes have a duration of somewhere between several hundred milliseconds to the order of 10 seconds. The person requesting the stop points out what is salient to him, described and interpreted the episode, and generated hypotheses to be tested in the remainder of the same tape and in the remainder of the database. The other person also provides his description and interpretation. The episode is discussed until all analysts in the room feel that there is nothing more to say about it at the moment—though subsequent periods of writing often turn up additional features, which would be discussed during some future meeting (in the situation with D. Middleton, this often occurred on the following day). In this way, we worked image-by-image through the video and, correspondingly line-by-line through the transcript.

When appropriate—e.g., when there is interactional trouble observable in the video—I hypothesized what might happen next before moving on to confirm or disconfirm the hypothesis. I then spent the following hours writing individual analyses, commented upon, confirmed or disconfirmed in the remainder of the database. I subsequently shared these analyses with laboratory members, especially with those unfamiliar with the dataset, who therefore served as disinterested peers reviewers as a means to increase the consistency and reliability of the analyses. Continuing the analysis, I both generated new hypotheses and categories and, simultaneously, (dis-) confirming existing ones. The results presented in this paper emerged from weeks of intensive analysis.

Analyzing the tapes from a first-time-through perspective assists researchers in avoiding teleological interpretations, whereby the outcomes of interactions are used to give sense to historically earlier interactions. This prevents me from providing sense to the moment of interaction that none of the participants could have had, because at the moment of their interaction they could not see what the ultimate outcome would be. For example, after having read the problem stem and talking about the graph for a short while, Annemarie turned to David and asked, "Is that right then?" (see below, Fragment 6, turn 33). At the outset, Annemarie, as all participants, would interpret a graph as part of a project that would ultimately lead to the design of instruction of graphs and graphing. She was asked to serve as an expert, and provide her reading of the graphs. But when she asked the question, Annemarie changed the frame. Although she could be seen as the expert on graphing in her own academic domain, Annemarie requested information from the research assistant whether she was right. I understood this as a problematic moment (interactional trouble) for the research assistant (David), for he had to deal with the attempt to change the frame whereby the presumed expert was asking questions rather than the other way around. Depending on the circumstances, I attempted to predict answers to questions such as "How is David getting himself out of this situation?" and "How will David respond to this request?"

LEVELS OF IN-FIELD AND OUT-OF-FIELD PERFORMANCE

Given the predominance of graphs in science and given that graphing is one of the quintessential scientific process skills, one might assume that scientists with PhDs (high publication rates, grants, and awards) would provide correct—acceptable to someone who teaches an introductory course in the discipline—interpretations of graphs taken from introductory textbooks, especially when these are from their own field. My study shows that this is not the case not only across domains but also within the domain. For the first analysis of graph interpretation, I present the levels of physicists' interpretations of graphs in both fields, physics and ecology, comparing the present to the results of ecologists of a preceding study (Roth & Bowen, 2003). Their interpretations are compared with the correct standard answers on some aspects of the graph, where standard answers are the kind of interpretations that university professors provide in their teaching about these and similar graphs (Table 1).

Table 1 shows the percentages of the correct, standard answers of physicists both in- and out-of-field. Paired *t*-tests were conducted for each of the three task pairs and evaluated at an alpha level adjusted according to the Bonferroni correction to correct for experiment-wise error rates due to multiple testing (i.e., $\alpha = 0.017$, $\alpha = 0.0033$, and $\alpha = 0.00033$). For the distribution graphs, the scientists did significantly better in the in-field than on the out-of-field task, $t(16) = 7.61$, $p < 0.00033$. There were 76% correct solutions on the in-field graph but no correct solution on the out-of-field graph. Using the identification of the two equilibrium points as performance measures, there was no statistically detectable difference between in-field and out-of-field performance on the dynamics graphs, $t\,(16) = 1.32$, $p > .017$. The mean score on all 4 items was $x = 1.53$, $SD = 1.37$. Finally, using the correct identifications of the three scenarios as measures, there was no statistically detectable difference between in-field and out-of-field performance on the isocline graphs, $t(16) = 0.80$,

$p > 0.017$. The mean score on the 6 items from the in-field and out-of-field graphs was x = 1.35 (23 correct for 17 physicists), $SD = 1.41$.

Table 1. Frequency of standard answers on the part of the physics compared to the biologists in a previous study

Task	Physicists (N = 17)		Biologists (N = 16)[1]		
			In-field		
	In-field	Out-of-field	University (N=8)	Public Sector (N=8)	Total (N=16)
Distribution					
Ionization/Adaptation	13 (76%)	0 (0%)	7 (86%)	2 (25%)	9 (56%)
Dynamics					
Unstable Equilibrium	8 (47%)	5 (29%)	8 (100%)	4 (50%)	12 (75%)
Stable Equilibrium	7 (41%)	6 (35%)	7 (86%)	3 (38%)	10 (63%)
Largest increase in N	- -	3 (18%)	1 (13%)	0 (0)	1 (6%)
Isoclines					
Compressible/ Essential	4 (24%)	5 (29%)	6 (75%)	2 (25%)	8 (50%)
Ideal Gas/ Substitutable	4 (24%)	4 (24%)	6 (75%)	2 (25%)	8 (50%)
Incompressible/ Complementary	4 (24%)	2 (12%)	6 (75%)	2 (25%)	8 (50%)
Summary Statistics	X = 6.67 SD = 3.73	X = 3.71 SD = 1.80	X = 5.13 SD = 1.69	X = 1.75 SD = 1.81	

Note 1: The data about the biologists has been culled from Roth and Bowen (2003).

To be able to compare the results of this study with that of my preceding study involving ecologists (Roth & Bowen, 2003), which involved individuals employed at the university and others working in the public sector, the mean performance on all standard answers were compared. For the biologists in the previous study, the university-based scientists tended to be more successful than non-university public sector scientists, $t(14) = 3.88$, $p < .01$, which I attributed to the difference in familiarity with the tasks—professors teaching undergraduate courses are more familiar with these kinds of graphs than public sector scientists not teaching introductory courses. In the present study, the physicists' mean frequencies of correct, standard answers on in-field graphs was not significantly higher than in out-of-field graph interpretation, $t(16) = 2.06$, $p > 0.05$. The in-field graph results of the physicists can be compared with that of university-based biologist group, because all of the physicists held university jobs. The percentages of correct answers in the biologist group tended to be higher than the in-field graph result of the physicist group. The mean frequency of correct solutions for physicists' out-of-field graphs was similar to that of non-university public sector biologists. I present the fuller explications of the physicists' interpretive practices in each task in the following paragraphs.

In the distribution graph pair, the fundamental problem appears to be what many physicists articulate as their lack of the context- and domain-specific knowledge. In the interpretation of the different plant distribution, one of the physicists explained the distribution using "evolution" as explanatory concept ("evolution has been done in such a way that some different plants have evolved to take advantage of a different niche"). Others did not explicitly use expressions such as the *differential adaptation* or the different *photosynthetic mechanisms* for the different types of plants, although all of the university biologists used this theoretical concept. But, for the different ionization energy in each shell distribution, most of physicists (76%) used an appropriate explanation (one that an instructor of an undergraduate course would accept) such as the definition of ionization or the binding energy of the atom. Some of them explicitly noted that the ionization energy cannot be inferred directly from the graph; in this, they articulated domain-related background knowledge that could not be gleaned from the graph itself. However, this kind of interpretation did not appear in the context of physicists' interpretations of biology graphs.

For the stability of the equilibrium points in the dynamics graph pair (Figure 1), the frequency of the standard correct answer was not significantly different for the in-field graph task. The videotapes show that in their interpretation of the dynamics graph pair, some physicists identified (stable, unstable) equilibriums. In the population dynamics graph, five (29%) physicists identified the unstable equilibrium point correctly and five incorrectly identified it as a stable equilibrium. One correctly identified it following active elicitation by the research assistant and one identified it as unstable using incorrect reasoning. Three physicists gave explanations for the characteristics of the intersection point (e.g., "steady state solutions to the population") and two did not comment at all. For the stable equilibrium point, six (35%) physicists identified it correctly and one identified it as an unstable equilibrium. One individual identified it correctly after the research assistant intervened, actively requesting an explication; one physicist described it as "convergent point"; and two called it a point of "equilibrium." Four individuals described the features of the equilibrium point (e.g., "the population is constant") and two refrained from commenting about the feature. Four physicists correctly identified the stability of both equilibrium points in the population dynamics graph. Three physicists correctly identified the largest increase of the population size as that point in the graph where the function $(b[N]-d[N])\cdot N$ was maximized; 11 physicists suggested that the maximum increase was where $(b - d) = (b - d)_{max}$, two thought the maximum was where $b = b_{max}$, and one pointed to the left intersection as the answer. One of those who mentioned that the largest increase occurs where $(b - d) = (b - d)_{max}$ explained that the three possible values of $(b - d) = (b - d)_{max}$ would be at very low N, at very large N, or somewhere in between.

In the physics dynamics graph task (Figure 1b), seven (41%) physicists correctly identified the stable equilibrium, and one of them named it "equilibrium," and the other called it "neutral equilibrium" (Table 1). Two individuals incorrectly identify it as an unstable equilibrium. Five physicists described the features of the equilibrium point such as "the forces are equal," "feels no force," "remains motionless or stationary," or "oscillates over some range of x" without, however, identifying the stability of the equilibrium point. One individual did not note any special features concerning the intersection of the two graphs. In sum, therefore, physicists generally were somewhat familiar with the concept of equilibrium: all except one noted some of the features of the intersection points in terms of equilibrium or related concepts, although they did not necessarily comment about the extent of the stability. Similarly, eight (47%) physicists identified the unstable equilibrium in the physics dynamics graph, one named it "equilibrium," and another individual wrongly denoted it as a "stable equilibrium." Four participants described features of the equilibrium point and one call it "a point of inflection"; and two individuals did not comment at all about the unstable equilibrium point. Six physicists noted the stability of both equilibrium points. In sum, therefore, only two physicists identified all the stabilities of equilibrium points in the graphs from both fields.

The third task consisted of triplets of isocline graphs. On both in-field and out-of-field versions, the frequency of correct answers was low (< 30%). One physicist provided the standard correct answer in all of the three biology isoclines graphs consistent with the concepts of "essential," "substitutable," and "complementary" resources. Two physicists provided a correct answer in all of the three physics isoclines graphs as the "compressible phase transition," "ideal gas," and "incompressible phase transition" cases. No individual provided the correct answer on all of the six isoclines. On average, then, physicists were correct on 2.35 out of the 6 aspects (39%) of the in-field graphs and provided 1.47 standard answers on the 7 aspects (21%) of the out-of-field graphs. In total, this amounted to 3.82 (29%) correct answers on the 13 aspects of interest. The physicists' success rates on both in-field and out-of-field graphs were similar to the response patterns of public sector scientists in ecology.

DIFFERENCES ACROSS DOMAINS

The physicists' interpretations of in-field and out-of-field graph differed in many respects. In general, they tended to draw on different types of graphical resources across the pairs of structurally identical tasks. When I began this study, I hypothesized that there might exist some clear patterns in the extent (time, words) to which participants engaged with the tasks across domains. The most dominant pattern was that the physicists spent more time and talked more on in-field graphs than on out-of-field graphs. From the total 51 in-field and out-of-field graph pairs, there were 31 pairs (60.8%) in which the participants spent more time on in-field graphs than on the corresponding out-of-field graph. The videotapes and transcripts revealed an obvious pattern: they talked more (had more to say) about the in-field graph than about the corresponding out-of-field graph. For example, one typical physicist produced more than twice the number of words in his in-field graph interpretation: From the total 7652 words he produced, 5212 words are uttered in in-field graph interpretations whereas 2440 words were related to out-of-field graph interpretations. The distribution of time/words across tasks was not constant, however: for the distribution, dynamics, and isograph sets, he produced 465/1897, 767/1790, and 1208/1525 words. A total of six physicists talked more about in-field graphs across the three tasks.

From a social practice perspective, the resources mobilized during performance are particularly important. Here, I articulate some of the differences in material resources—e.g., axis labels, units, and scales—physicists used for their in-field and out-of-field graph interpretations. In a Cartesian graph the axes constitute important structures that may hinder or facilitate interpretation. In this study, nearly all physicists explicitly articulated the nature of the axes during the beginning stages of each task. There were more variations in out-of-field graph than in in-field graph in confirming the axis, although there were differences in the degree to which the axes were represented in each task. I exemplify the findings with materials from the distribution graph pair depicted in Figure 1.

In the dynamics graph pair, there are no scales or units on either axis of the biology dynamics graph axis; but there are axis labels “rates” (vertical axis) and “N.” The structurally equivalent task from physics includes concrete numbers on the horizontal axis labeled “x.” On the vertical axis, there are concrete numbers and labels referring to force functions without any other labels or units. These differences are possible mediators for variations across the two tasks. My videotapes show that in their interpretations of the abscissa of the biology dynamics graph, eight physicists asked questions about the nature of “N,” despite the fact that this letter is used in many fields to denote numbers, population sizes, and densities. Four physicists suggested that the letter denoted “population,” one thought of it as population density, one treated it as population size, and one used it as “some [generic] parameter.” Two did not make a comment concerning the nature of the abscissa. One physicist attempted to confirm with the research assistant whether he could assume the two axes to be linear and he wanted to know whether the intersection of abscissa and ordinate identified the true origin of the grid. For the ordinate label “rates,” two physicists made explicit references to it. One physicist furthermore suggested that “rate” had to be associated with particular units and continually referred to the slopes of the curves, to distinguish “rate” (as in “birthrate,” “death rate” from “change of the rate” (as in slope of the two curves). Another physicist tried to express *rate* as a particular number with a particular unit, and using a concrete unit is, to him, a way of making sense:

> well, no, to make any sense at all, this [rate] would have to be death rate per ten to the fifth or ten to the fourth per some number of population. Otherwise it wouldn’t make sense at all. This would just be per second or per year or per something like radioactive decay, so this death rate to have any sense presumably has to be per some number of the population. Presumably, because one of the population is highest here, I mean this is almost flat, the first approximation except there is no– this is a linear scale, presumably, right?

The double nature of the “rates” involved gave rise to considerable interpretive problems that a number of physicists—including the one featured in the case study below—could not satisfactorily resolve. Thus, the commonly used term “rate” refers to the slope of a function, which in the present case are birthrate and death rate. But because the two functions depend on the variable N, the slopes b' and d' of the functions at any one point are given by the differentials $b' = \partial b/\partial N$ and $d' = \partial d/\partial N$. Each function, however, also is a derivative of the population with respect to time, that is, $b = \partial N^{+}/\partial t$ and $d = \partial N^{-}/\partial t$. The derivatives of the two functions displayed are therefore $b' = \partial^{2}N^{+}//\partial N\partial t$ and $d' = \partial^{2}N^{-}//\partial N\partial t$. It is this double dependence of two rates on time and on the population size (density) that appeared to have been at the origin of the troubles for these physicists.

In the physics dynamics task, the legend of the attractive force functions on the ordinate tended to confuse a number of the physicists. In some instances the research assistant explained in advance that the legend represented two simultaneous plots of force functions.

Nearly all participants took the vertical axis to represent forces or force functions. Five used it as a magnitude or strength of the force. Most of the physicists took the "x" on the abscissa as position or location or displacement for granted—which is one of the standard ways in which distances are denoted in the field, especially in the one-dimensional and two-dimensional cases when the problem does not ask for radial coordinates. One individual asked whether the graph represented the magnitude of the force in time—similar to the interpretation of "N" as time found among biologists (Roth & Bowen, 2003) and related to the problem of understanding "rates" as functions of time. One physicist initially interpreted "x" as denoting the distance between the two forces and then changed repeatedly how he referred to the sign. Seven physicists explicitly talked about the scales or units and two suggested that the scales were "weird." One physicist expressed himself for an extended period about the fact that the origin of the graph was not in the middle, and finally made the assumption that the center would be the origin ("zero").

CONTINGENT NATURE OF INTERPRETATION

In this section, I provide a more global picture of the contingent nature of graph interpretation by following several scientists across the different in-field and out-of-field graphs. To get a better understanding of how particular interpretations actually emerged, I provide a detailed case study of the beginning of one graph interpretation session in the subsequent section.

From a social practice, graphs are but material resources that are mobilized in and through agency for the purposes at hand, which are realizations of collective possibilities and motives. Any conscious action inherently is understandable, because human beings have grounds for actions that can be verbally articulated, and language "is a practical consciousness-for-others and, consequently, consciousness-for-myself" (Vygotsky, 1986, p. 256). In this perspective, the relationship of a graph to its interpretive referent, which is a fundamental relation onto which other relations are grafted during interpretations, is the result of social practice and cannot be deduced from a graph independently of the context of its use. More importantly, it is a thing that cannot be detached from the language generally and words particularly, and in this impossibility, it becomes a social phenomenon such that cognition inherently lies inside and outside, at and across the individual | collective boundary: "The word is a thing in our consciousness . . . that is absolutely impossible for one person, but that becomes a reality for two" (p. 256). That is, the interpretations bear all the marks of the sociality of the research session—think aloud protocols/interview sessions—and cannot therefore be taken as evidence of skills independent of this context even though the participants may draw on their prior experiences and knowledge as resources for coping with the present tasks (Roth & Middleton, 2006). I suggest that graph interpretation is not just the result of a deployment of embodied context-independent cognitive skills but that it constitutes a highly contingent and therefore context-dependent practice. (This is so because the dispositions to act and the current field are mutually constitutive: What is perceived is a function of the dispositions and the particulars perceived activate certain dispositions, see Bourdieu, 1990.) In other words, physicists' graph interpretations are situated in the context of each in-field and out-of-field task and in the interactions with the interviewer and are contingent on the resources the physicists bring with them to the tasks. At the same time, the singular productions in the various sessions realize *collective* possibilities in a concrete way, and therefore are not so singular at all: the verbal productions could not be understood unless they were already embodied as possibilities on the part of the listener (research assistant) and the analyst (me).

To exhibit how their interpretation is situated in the context of the task, I present several examples selected on heuristic grounds from across tasks. Thus, on the biology distribution graph task, one physicist started his interpretation by looking at the axes and then one-by-one talked about the three elevation-dependent plant distributions. He completed his spontaneous interpretation within three minutes by saying "that's all about I can say about that particular graph." It can be seen in the following that he explicitly expressed the correlation between two curves labeled C3 and CAM, although he could not explain further the reason underlying their distribution.

> The c-three here seems to be very much uh, important at the higher elevations two thousand and comes down to, to a minimum but it does seem that to uh, increase again at the uh, hottest and driest. So, so it's a little bit hard to tell exactly uh, whether there is an exact correlation between the elevation and weather, it's hotter, drier, cooler. So, the reason for the dip in the C-three curve I guess, you know that will require further examination. On the other hand, the CAM plant seems to flourish most best at that elevation where the dip occurs in the c-three curves, so there must be a sort of negative correlation between those two types of plants.

In his biology dynamics graph interpretation, this physicist asked what "N" was while looking at the graph and caption. Before he proceeded to articulate an interpretation each of the three regions defined by the two intersection points, he pointed out the inconsistency between the caption and the form of the graph. The interactions that constitute the meaning of the graph can be seen more dramatically in the biology isoclines graph. He started his commentary with the utterance, "Oh, god! I'm not used to this type of graph. Okay. This is, okay. The amount . . . so I have to learn to interpret these." He inquired about what the graphs represent through reading the caption repeatedly, pointing out or tracing the related parts on the graph plate with frequent long and short pauses. After 4 ½ minutes and after several failed attempts at producing an interpretation, he finally asked the research assistant guiding questions including "I'm puzzled by exactly what the significance of the graph actually is. You got some questions that might lead me." With the help of the interviewer's leading comments, he finally described the problem:

> Yeah, okay. But the problem, the problem that I am seeing, I mean, why your trend i-, what, heuh ((sighs)), what your trend is supposed you can see in this particular one is uh, you got two variables and you want a third dimension. Okay, now, that's a problem, we always have. I would say that a probable, that's a very common situation physical scientists as you got two, two variables and then you got your function itself, might need a plot things three dimensionally, in physical chemistry, well, what we do this, we, we would plot at a weak view, and then on hell, we'd sketch a third. With the modern uh, graphics package, you can actually plot them in three-dimensions uh, and so what you have to, while you do, but sometimes you reduce them to two dimensions by doing projections. Oh, okay, now, let me see ((6 second pause)) but what, what actually puzzles me in this particular, I haven't got a

> clear idea in my own mind as to what, okay, if we're at a third dimension, what uh, what would we be plotting and what would we be projecting, okay, so, okay.

Although the situation of plotting three dimensionally is very common in his own field of physical chemistry—after all, the p-V-T diagrams used for the in-field representation is a basic element of any introductory course in the field—this physicist expressed experiencing difficulties in forming a clear idea as to what the graph really means. Immediately following this episode, it was in and through the interaction with the research assistant that this physicist was led to plot a three-dimensional graph. Only after drawing this three-dimensional graph changed the situation did the individual come to provide a correct reading for the three cases of biology isoclines. This again shows the extent to which the available *social* resource, the conversation with the research assistant, allowed him to change his reading to one that is accepted in the field. Some readers may think about this event as a weakness of the study, but it turns out that even under the most rigorous control for the contextual factors, interview and survey researchers is marked by the social interactive nature of the data collection process (e.g., Suchman & Jordan, 1990). Even if the researcher were required not to speak at all, we would still have to take into account the orientation of the participant (e.g., Bakhtin, 1986), who is speaking *for* and *to* the researcher, and who uses language that came to him or her *from* the generalized other and, in and through this session, returns to this other.

A similar kind of contingency of the task and interactions among available resources and interviewer can also be found in the in-field graph interpretations. For example, before starting the interpretation of the physics dynamics graph, the physicist had a long discussion with the interviewer about the scale of the abscissa, because there are concrete asymmetrical numbers on both ends of the x-axis. But, in his physics distribution graph, he identified the graph as "density versus distance from the nucleus" from the origin and provided a more detailed identification of the graph ("this is a prediction of the probability density finding an electron at a given distance"). Concerning the physics isoclines graph interpretation, he expressed the family resemblance between the two graphs that made a pair:

> Okay, we're back to one of these things again, Okay. But at least we've solved that. Okay. You know we had plot things three dimensionally, okay, so we got Vee-one and Vee-two are two variables plotting um, and then we've got curves again which are gonna be three dimensional projections, okay . . . well, it goes back to the same thing on that plant nutrient basically-

After pointing to the similarity between the two tasks ("we're back to one of these things again"), he talked about the three sets of isoclines in terms of real-world phenomena in his own field, such as ideal gases, incompressible liquids, and compressible liquids. He ascribed to the graph aspects of things that he was familiar with in his everyday life.

On the biology dynamics graph one individual referred to two intersections without explaining stabilities and proceeded to talk about the three regions defined the two intersections. Another physicist began by interpreting the three regions from right to left. In the interpretation of the middle region, he identified two intersections "a" and "b" as stable equilibrium at first, but whereas he explained the population change in the middle region, he caught himself and corrected "b" to be a stable equilibrium and "a" an unstable one. A third individual did not mention the stability of intersections, but merely explained one of the properties of equilibrium: "if the birth and death rates are equal presumably, the population is constant." A fourth physicist used a particular example of "rats in the cage" in his biology dynamics graph interpretation of the three regions from left to right. He added the general interpretation in the order of middle, right, and left graph sections. In the interpretation of physics dynamics graph, I analyzed their interpretation structure in similar way as in the biology dynamics graph. For example, a fifth physicist started in the left section and described the properties of particle movement around the left intersection and then unfolded his interpretation of the particle movement according to its initial momentum and starting point. His interpretation did not distinguish the three regions. Another individual divided the graph into two regions: where there is only a rightward force and where the two forces act simultaneously. He described the intersections as a case where the sum of the two forces is zero. He completed his interpretation by talking about the energy of across the three regions. All the other physicists' structure of dynamics graph interpretation can be understood similarly. The interpretations exhibited different structures in the interpretation of the biology and the physics graph. In the biology dynamics graph interpretation, five of them changed the focus in the order of the left, middle, and right sections. Four individuals structured their interpretation in this order: left and right regions, then the intersection points, and then the region between the intersection points.

These results show differences within and between pairs of tasks. No two physicists enacted the same sequence through the different graph regions. Thus, two physicists who took the same sequence of left, center, and right regions in their interpretation, differed in the structural details of their interpretations. A third individual pointed out the two intersection points, did not mention their nature as equilibrium points, and then explained the change of the population by comparing birthrate and death rate in the left and center regions (as defined by the intersections in Figure 1), and evaluated each situation. She continued to the area to the right of the right intersection, but did so only to compare the birthrates and death rates. She returned to the left section of the graph and talked about the reason of higher death rates in the left section, and then proceeded to the center section of the graph defined by the two intersections. She did express trouble identifying where the population increases. She did not articulate population change in the right section, but she asked the research assistant why the death rate was higher than the birthrate and expressed interest about the biology of that phenomenon. Another physicist compared the birthrates and death rates in the three sections. He then compared the death rates and birthrates at the two intersections. He talked about the change in population size in the three sections from right to left and finally summarized the population change for left section compared with that of right and center sections.

In sum, then, whereas the performances of the experts sometimes are thought to be more or less homogeneous—the very notions of practice and community of practice suggests commonalities not shared with other practices and communities—this study is consistent with others that find considerable within and between expert performances, some even pointing to the occurrence of better performances by non-experts (e.g., Abel, Lima Silva, Campbell, & De Ros, 2005; Shafto & Coley, 2003). Whereas the results so far pointed out the rather low performance levels and the heterogeneity and contingency of the interpretations, I have yet to focus on the concrete details and relations from which the individual sessions evolved in the dialectic tension between (social, material) resources, which constitute affordances and constraint, and the agency that mobilized them. This is the topic of next section.

THE WORK OF STRUCTURING A GRAPH READING TASK: ANATOMY OF A PROBLEMATIC GRAPH READING

In a previous section, I show that the number of physicists who provide interpretations of entry-level graphs in physics (in-field) and ecology (out-of-field) is rather low. The graphs clearly did not encode 10,000 words of experts but rather constituted unfamiliar and foreign entities that resisted these experienced scientists' efforts in making sense. Or, to put it in a tongue-and-cheek perspective, in many instances even 10,000 words were insufficient to produce graph readings that were consistent with the canon of the field. Existing models of graph interpretation in the field of cognitive science often take cursory descriptions of graph interpretation sessions as their point of departure, thereby failing to take into account the microlevel details of *actual* interpretation sessions that tell us a lot of what *really* rather than possibly happens in the interpretations. How can we get access to what actually happens, as seen by those involved? More poignantly, how can we get access to processes that are invisible—and perhaps compiled—in the performances of experts? That is, I am asking here for how we can access to a life-world perspective that some in artificial intelligence already embody in their modeling efforts (Agre & Horswill, 1997). In some existing cognitive science studies, what experts say (after the fact) that they are doing is taken as fact. Yet there is mounting evidence that what expert scientists, engineers, teachers, and other practitioners say they have done and what they could be seen as doing is often very different (e.g., Bourdieu, 1990). In some social sciences, it has been shown that methods normally hidden from view come to the fore and are mobilized when experts are in trouble, in situations of "breakdown," when their ordinary ways of functioning no longer work so that in the attempt to accommodate participants exhibit their methods of and for social conduct (Garfinkel, 1967). Rather than observing experts in situations where they provide unproblematic accounts of what they have done, an appropriate research method puts them—often with peers—into situations where they make available all those skills and procedures that really constitute their expertise (e.g., in the control room of the London Underground [Heath & Luff, 2000]). To show what is salient and how experienced physicists interact with the graphing tasks in my study, I provide an ethnomethodologically and conversation-analytically informed study of the first 7 minutes of one session. Any good model ought to be able to predict both efficient as well as incorrect performances, on the part of experts and non-experts alike. I provide the account in part as a test bed that others may be able to use as a standard for graph interpretation models.

The session concerns the ecology dynamics graph and Annemarie, a 30-year veteran of her department whose teaching skills have been rewarded through university-wide awards. In this session, we see her articulate the difficulty of ordering the display sufficiently for getting a good handle on the problem. When she eventually began to find an orientation, the resource most salient to her are the slopes of the curves, ultimately leading her to produce an interpretive text that was inconsistent with the scientific norm. She expressed a lot of uncertainty about what she perceived and what she did and, to decrease this uncertainty, she engaged in repeated attempts to receive feedback on her progress—counter to the protocol that she nevertheless had agreed to prior to the session.

"I Can Hardly Absorb What That Means"

As a participant approaches a task, it initially is unstructured, though as soon as the eyes are laid on the sheet, structuring beings to operate and separate out the different parts. The work of structuring the text, however, requires reading, which therefore unfolds in time. As it unfolds in real time, reading has to structure what initially is nothing but a "flat" text—this would be apparent if the text had been read by a text-to-speech program currently available on many computers. It is immediately apparent that the voice is not a human one because the prosodic cues that allows listeners to structure hearing are considerably off normal. Intonation, as made available through the different prosodic parameters, is an important means to structure, for ourselves and for others, any form of text that thereby obtains its meaning (Vološinov/Bakhtin, 1973).

The session pertaining to the population dynamics graph begins when Annemarie changed the sheets in front of her over to the second task featuring the dynamics graph from ecology. At this point, her right hand moves toward the caption, the pen stopping on the top right corner (Figure 2). After several seconds, she asks whether the research assistant wants her to read aloud. From the perspective of conversation analysis, it is a question because the research assistant treated it as such: he responds in the preferred affirmative, "sure, if you'd like to" (turn 002).

Fragment 2
```
001  A:   do you want me to read it out loud?
002  D:   sure, if youd like to
```

In this situation, Annemarie asks David whether she ought to read aloud although she has been instructed to do so earlier and although she has already done so on the preceding task. At the same time, the question–answer sequence ascertains that Annemarie is familiar with the experimental condition that asked participants to think aloud while providing a reading of the graphing tasks.

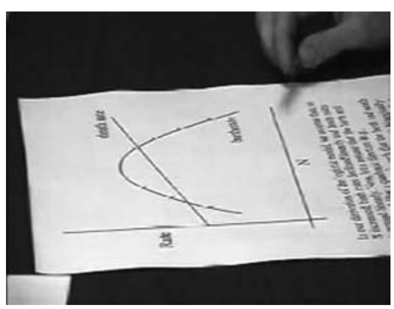

Figure 2. The hand/pen combination moves to the text when the scientists are oriented toward it; but the responsibility for the text always is attributed to the researchers.

Annemarie then goes ahead reading aloud the caption in a stop and go fashion, including long pauses (1.41, 1.33, 1.68, 4.50, 1.74, 1.72, 2.04, and 1.66 seconds), where I heuristically take the one-second rule as a heuristic for denoting something as a long pause: In conversations as well as in school science classrooms, the maximum pauses normally do not exceed one second (Jefferson, 1989). More so, the voice is strongly modulated, the pitch jumping repeatedly upward, the speech intensity changing from relative piano (low volume) to higher levels, and to points of almost disappearing. This continually changing production of the text in and through the utterance is evident in the following fragment 3 taken from the early part of the session while Annemarie is still reading the caption.

Fragment 3

```
012         (1.66)
013   A:    <<p>focus on the birth and death rates (0.70) at the two
            intersection points of the lines.> (0.93) and on ‘what happens
            to ^population sizes in the ↑zones of population size ‘below
            (0.64) be↑tween an ab↑ove the inter[sec]tion
014   D:                                       [uum]
015   A:    points.
016         (1.20)
017         .HHhssssss. <<f>i can hardly absorb what that means.>
018         (2.02)
```

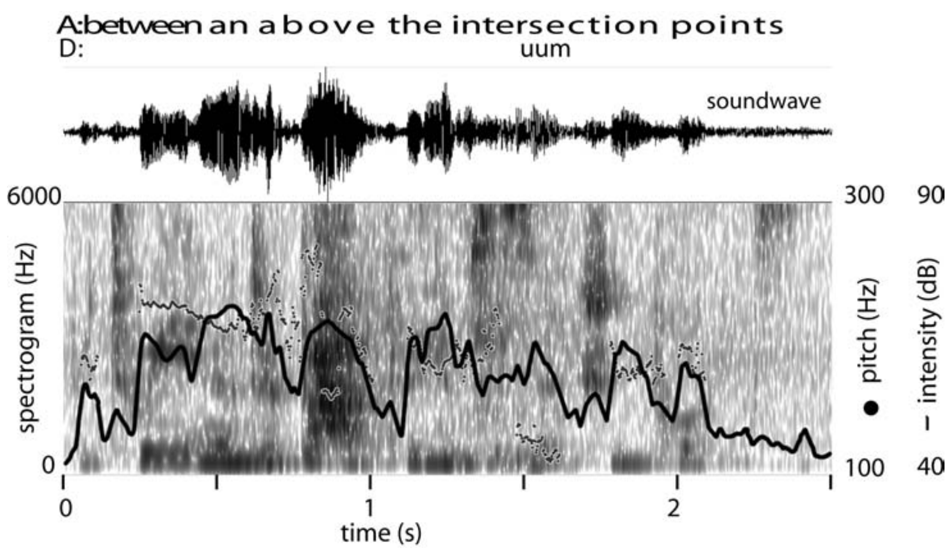

Figure 3. Sound wave, speech intensity, pitch, and spectrogram for a stretch of talk ((turn 013).

As shown in Figure 3, there are considerable variations in several parameters of the prosody, including pitch, speech rate, speech intensity, energy distribution across spectrum, and so on. Because these variations co-occur with the sounds that we hear as words, the latter can be heard with continually changing intonation, emphasizing some words, deemphasizing others, making it clear that the listener is addressed or speaking with such a low volume as if the speech addresses the speaker alone, and so forth. That is, a first level of structure arises in and from the prosodic variations that both lend and constitute differential emphasis to different parts of the text. There are several jumps in the pitch, which can be heard as emphases of the syllable heard. At one point in turn 013, the production of the word overlaps with a break in the voice, resembling a cackle, following which the voice fades away (Figure 3). The figure also shows—in the spectrogram—that there is a sudden shift of the sound energy into higher frequency ranges—as indicated by the dark areas at higher frequency ranges—associated with the cackle and a jump in the pitch to higher values during the production of the word “above” (turn 13, Figure 3). Finally, the rendering of the utterance above the sound wave shows a change of the delivery rate, as letters come to lie closer or farther away from one another.

Although this is an introductory level graph, Annemarie does not just “rattle off” a reading to produce an interpretation. There are pauses as if Annemarie wants to give herself time “to absorb” the meaning of the words she has just read. Evidence for the pauses is seen in turns 012, 016, and 018. The pauses can be heard and experienced as moments of gathering up. There are other, shorter pauses visible within turns (e.g., turn 013). These pauses punctuate the production of text when Annemarie actually reads. Twice in the fragment, however, Annemarie provides us with evidence of exasperation, which, as she explains, comes from the text that hardly allows her to absorb what it means (turn 017).

The effect of the modulation of the voice parameters is a structuring and commentating. Thus, the increases in intensity, increases in pitch, and changes in the delivery rate can be heard as emphases or de-emphases to the text. The cackle during the production of the word “above” can be heard as a commentary to the reading not directly available in verbal form, but subsequently taken up in the text itself. It is a social evaluation in the concrete utterance unavailable in the text itself but rendered public in and through the intonation (Bakhtin/Medvedev, 1978). Thus, in turn 017, Annemarie comments that she “can hardly absorb what that means,” where “that” refers to the text that she has been reading, a reference further ascertained by the hand position pointing to the caption (Figure 4). We can therefore see in the cackle the growth point of a meta-idea, Annemarie’s understanding of the difficulties she has in understanding what the task as a whole and possibly the text in particular means.[2] The transcript also shows that the production of the utterance involves intensities much higher than that of the surrounding talk; the intensities move to a low volume (i.e., piano) right after Annemarie returns to the reading of the caption. Here, the piano-level intensity expresses an orientation where she is reading more for herself rather than to the researcher, whereas the normal and higher speech intensities are oriented toward the other.

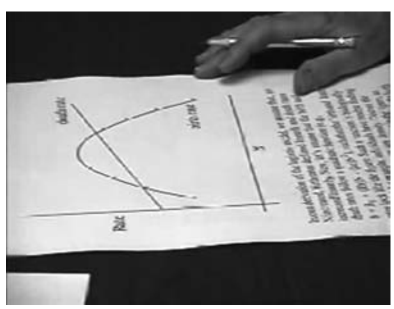

Figure 4.The hand placed near the text exhibits orientation to an aspect of the task that the researcher is responsible for (e.g., Roth & Middleton, 2006).

In essence, therefore, the first few moments provide considerable evidence for the work of structuring required in making sense of the task. Annemarie is struggling to impose

[2] In dialectical approaches to psycholinguistics, growth points are whole units that embody meaning but in an underdeveloped, germ-cell-like fashion (McNeill, 2002). As speech unfolds, meaning comes to be more fully articulated by verbal means. Analytically, growth points are identified after the fact by means of backtracking from the fully articulate and evident meaning to the point that there is a first sign for its appearance.

structure in and through her reading and to articulate an initial interpretation of the caption/instruction. This concern for an understanding of the caption/instruction, which she defines as the "trouble to get out," is also evident in the moments that follow, as shown in the next section.

"I'm Having Trouble Getting Out"

In the following fragment, we can directly observe the shift associated with an instruction available in the caption, and therefore an orientation toward what the task specifies *her* to do, and therefore, to her domain of responsibility (Roth & Middleton, 2006). Across the turns 019 to 021, we can clearly hear Annemarie reading, and, together with her hand position (Figure 4), understand her to be oriented toward the text. But as she reads the text "focus on the birth- and death rates at the two intersection points" (turn 021), she moves her pencil to the upper (right) intersection point and pauses (Figure 5), which we can see as a shift in her orientation to the task itself.

Fragment 4

```
019       <<pp>discuss the implication of the birth and death rates in
          the figure as regards conservation of such a species.>
020       (2.80)
021       <<pp>focus on the birth and death rates at the two intersection
          points of the [lines,
                                           [((moves pen to upper intersection))
022       (3.23)
023       and on what happens to population sizes in the zones of
          population size below, between, and above the intersection
          points.>
```

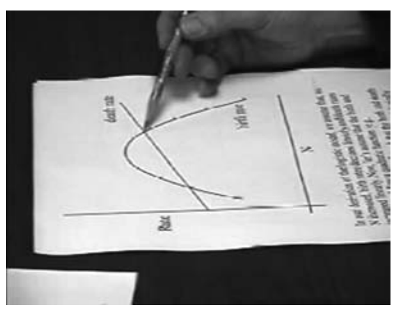

Figure 5. A part of the text ("focus on the birth and death rates at the two intersection points") turns into an instruction, clearly observable in the

The fact that Annemarie has changed orientation toward the graph and to the intersection point should be understood not as the mere realization of an instruction, but as a form of behavior the description of which is appropriately described by the instruction ("focus on . . ."). There are never linear and causal relations between "instructions" (plans), on the one hand, and the situated actions that realize what the instructions (plans) describe, on the other hand (e.g., Suchman, 1987). Rather, the text prospectively configures the behavior without being able to *determine* it, as we know from other sessions that reading the same text does not cause the participant to orient immediately to this part of the graph. In fact, in numerous instances on my videotapes, the graph interpretations do not deal with the intersections as locations where the graph is sectioned into three areas at all. Whether participants implement the focus on the intersection points therefore is an empirical matter.

A long pause follows (turn 22) before Annemarie continues reading the caption with very low voice intensity but leaving the pen at the intersection (as in Figure 5). At this moment, therefore, there is a double orientation. On the one hand, her gaze has returned to the text, which she continues reading with very low speech intensity, almost inaudibly. (We can hear this also as indicating an orientation to the experimenter, who knows the text, and for whom the text itself therefore does not have to be read.) On the other hand, her pen rests at the intersection point, like a marker of the object about which she is being asked after she has focused on the intersection. That is, the pen continues implementing the focus that she has been asked to enact, or rather, she acts in a way so that we can now say that "focus on the intersection point" is a description of what she has done. In fact, the pen is an embodied pointer to an aspect of the setting, which she does not have to keep in mind and mentally track because both feature and pointer are materially present in the situation where she can find both whenever needed. This dialectical double orientation makes the text to be about the particular aspect of the graph.

Annemarie is still focusing on the text that is asking her to focus on the intersection points and "on what happens to population sizes in the zones of population size below, between, and above the intersection points" (turn 023). In this instance, as she is reading the end of the text, the pen moves repeatedly vertically up and down (Figure 6). That is, here we have a text and a gesture produced simultaneously, which therefore can be seen and heard as part of the same meaning unit (McNeill, 2002). However, this meaning unit, if it denotes a vertical direction for "below, between, and above the intersection points" is not that intended by the instructor of the course from which the graph was culled or by other instructors using the particular graph. The "correct" interpretation of the prepositions is a left-right orientation on the graph, which corresponds to increases and decreases in the population sizes (densities) denoted by the letter *N* on the abscissa. Here, the instruction and the situated action no longer overlap, at least for this very instance at which the pen moves vertically while the words "below, between, and above" are being uttered. There is therefore both a dialectical, inner contradiction between text and gesture, on the one hand, and a logical contradiction between the spatial relations denoted in the text and that denoted by the gesture, on the other hand.

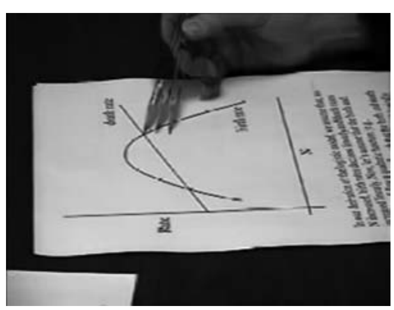

Figure 6. The instruction "below, between, and above the intersection points" is associated with a repeated vertical movement of the pen.

In the long pause that follows (16.37 s), the pen enacts the vertical up-down movement for a second time (as in Figure 6). She appears confused. As Fragment 5 shows, after a 11-second pause, Annemarie moves the hand with the pen downward to the text where she places the pen tip to the right of the first paragraph and the left hand to its left (Figure 7). She has oriented from the graph to the text, apparently seeking further assistance, and then asks the research assistant a question about the text.

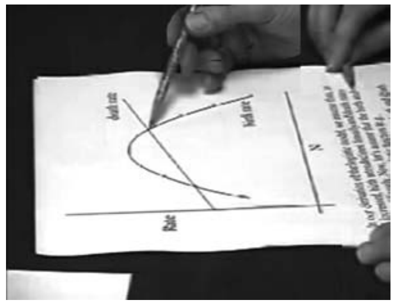

Figure 7. This overlay of two offprints shows how, after pausing to speak for a while and oriented toward the graph, Annemarie returns to the text, a shift in orientation flagged by the change in hand/pen positions.

Fragment 5

```
023       and on what happens to population sizes in the zones of
          population size below, between, and above the intersection
          points.>
024       (16.37) ((after 11 s, the hands move from the graph to the text
          [Figure 7]))
025       so the first sentence <<p>is not (0.20) relevant to this right?
          (0.20) i=am> i=m having trouble (0.15) n::='GETting ^out
          ((movement along text with pencil)) (0.37). <<pp>as long as> i
          need it further away. (0.47) ((Literally moving paper further
          away.)) .hhh whats here?
```

In asking the research assistant about the relevance of the text, Annemarie clearly attributes the responsibility for it to him, a pattern found across the database (Roth & Middleton, 2006). There is text, but, in her assessment, it is not relevant to the task itself. If it is indeed irrelevant, then it constitutes either bad practice or—because all social action is considered to be driven by motives—a deliberate distracter used in a task designed for psychological research purposes rather than reflecting the authentic practices of science. That is, in these particular situations, it appears legitimate to ask questions, as the queries pertain to the caption below the graph to be interpreted, and this text also contains the instructions. When the text generally and the instructions specifically do not appear to be clear, queries are frequently oriented to the research assistant and not treated as illegitimate to the think-aloud protocol described to the participants beforehand. In this instance, the query is followed by a statement about the task in progress "I'm having trouble getting out," where a particular emphasis is placed prosodically on the "getting" and a somewhat smaller emphasis on the "out." Annemarie then suggests that she needs "it further away" and then moves the task sheet away from her and lifts it off the table (Figure 8). That is, she literally moves away from the text in an attempt to get out of it, metaphorically speaking, acquire some distance, and, perhaps, approach it in a new way from the distance gained.

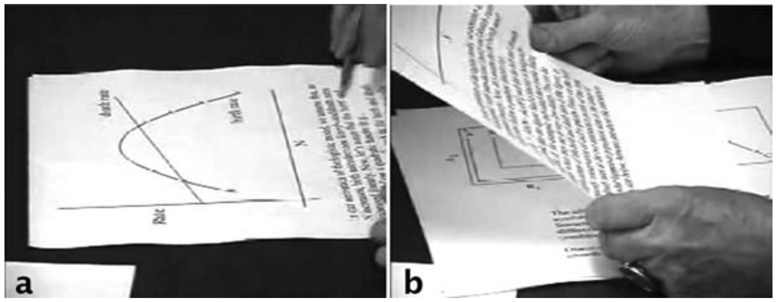

Figure 8. Annemarie formulates that she needs the paper "further away" to overcome her "trouble getting out." a. This overlay shows how she moves the hand/pen downward while uttering "getting out." b. She moves task sheet away and lifts it off the table.

Here Annemarie articulates "having trouble getting out," while her hand is next to the text. The responsibility for the text is that of the researcher (Roth & Middleton, 2006), and the responsibility for the difficulties therefore are rested with the researcher—as this and other studies have shown where the graphs were denoted as bad, poorly designed, and other negative adjectives by scientists from the discipline of ecology (Roth & Bowen, 2003). Responsibility for the trouble thereby is transferred at least partially to the researcher, who had constructed this text that Annemarie "can hardly absorb what it means" (turn 017) and from which she "has trouble getting out." Eventually, however, Annemarie orients to the task as she perceives it; and here, as the next section shows, what is most salient to her are the slopes of the two curves rather than their heights, as required for a correct interpretation of the graph.

Focusing On Slopes: "Is That Right Then?"

After another long pause (17.42 s), during which she stares at the paper, Annemarie re-reads part of the text and then, by means of a much louder and heard as a resolute "So," begins a reading of the graph itself. She places the task sheet on the desk and begins to gesture with her pen over different parts of the graph and then with uttering "death rate" (turn 031), articulates a first description of the graph, "death rate increasing and the birthrate increasing and the birthrate is increasing faster than the death rate" (turn 031). As she speaks about the death rate and birthrates, she moves the tip of the pen along the corresponding lines across the left intersection point (Figure 9).

Fragment 6

```
029     ↑here ((pencil to the graph)) (.) we have the
030     (2.07)
031     death rate increasing (0.69) and the birth rate increasing and
        the birthrate is increasing (0.57) faster (0.95) than the death
        rate.
032     (1.71)
```

```
033       so they=re both increasing but the birthrate invar is faster
          increasing than the death rate so presumably that means that
          the population is increasing. (0.93) is that right then?
```

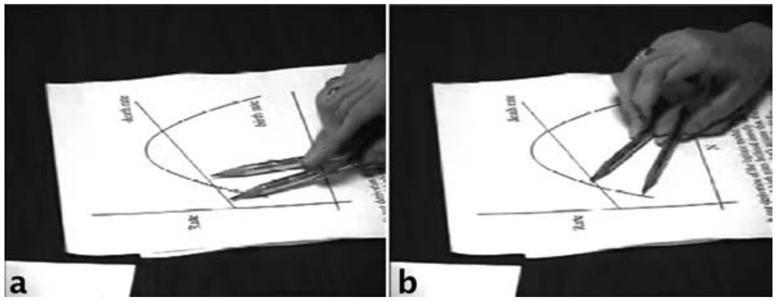

Figure 9. As she describes the behavior of the two curves, Annemarie moves the pen along the line currently being talked about. a. The pen moves with the utterance "Death rate increasing." b. The pen moves after Annemarie verbally articulates "birthrate is" and while she utters "increasing."

In this instance, it is apparent that what is salient to Annemarie are the slopes of the two curves rather than their heights; and her pen movement suggests that this salience occurs across the intersection point. That is, she does not act as experts have been described to act in this type of graph. Thus, in economy, the corresponding graph would show an intersection of supply and demand curves with an equilibrium situation around the intersection. According to an existing study of graphs with equilibrium points at intersections, experts do not focus on and interpret the slopes but rather the relative values of the curves on either side of the intersection point (Tabachneck-Schijf et al., 1997).[3] In fact, in the supply-demand graphs, experts apparently compare the two curves above and below the intersection point *with respect to the ordinate*, whereas in ecology—despites the influence economic models have had on its theories and graphical models (Kingsland, 1995)—the two curves are compared above and below the intersection point *with respect to the abscissa*. In the present instance, it is not only the verbal text that describes the curve as increasing, but the gesture with the pen tip following the two curves also enacts the observable increase as the hand and gaze moves from left to right (Figure 9).

After a pause, Annemarie resumes by first summarizing, "so they are both increasing but the birthrate is faster increasing than the death rate," and then states the conclusion, "so presumably that means that the population is increasing." We note the hesitancy, "presumably that means," which allows the inference to stand provisionally rather than making it an established fact. Indeed, Annemarie is uncertain about the conclusion and, counter the experimental condition that asked her to think aloud until she has reached her conclusions, she asks the experimenter to provide her with feedback, "Is that right then?" (turn 033).

At this point, then, her conclusions are unexpected. Annemarie clearly has pointed to the two graphs as increasing *across* the intersection and has described both graphs as *increasing*, though the birthrate is increasing *faster* than the death rate. The inference she draws from the "faster" increase is that the population is increasing, which, as a quick comparison of birthrate and death rate to the left of the intersection shows, is not the case: here, the population would

[3] The economist does not interpret the supply-demand graph (see below) by comparing the relative heights of the curves to the left and right of the intersection bur rather compares the graphs on ordinate values above and below the intersection.

be decreasing because the latter exceeds the former. We may ask at this point, "Will Annemarie recover from this error?" and "Will there be further evidence for the fact that the slope of the curve rather than the relative heights of the curve to the left and right of the intersection are salient in and to her perception?" Cognitive models are only good if they are predictive, and the CaMeRa model proposed elsewhere suggests that "experts" perceive the relative heights rather than the slopes in curves such as the ones presented here (Tabachneck-Schijf et al., 1997). If the CaMeRa model only predicts the behavior of the one expert who constituted the test case, then it is even more limited as it would not describe expertise in general. In particular, the CaMeRa model does not specify why the economy expert focuses on the comparisons of the two curves with respect to the ordinate, whereas the experts in other disciplines focus on the comparison of the two curves with respect to the abscissa. Thus, there appears to be a difference not only between the economist in the Tabachneck-Schijf et al. study and the ecologists in my own previous study (Roth & Bowen, 2003), but the same difference exists with respect to the physicists in the present study, as the latter also tended to compare the two graphs in the left-right rather than up-down directions. Pertaining to the directionality, we may further ask whether Annemarie will continue to treat the left and right of the intersections indistinctly or whether she will distinguish the two sides. The brief exchange with the research assistant that followed her query provides further evidence of what she perceived.

As the beginning of Fragment 7 shows, there is a pause. Then the research assistant harrumphs. There is another pause, which Annemarie breaks by uttering with a rising intonation toward the end, "round this region" (turn 037), during which the research assistant harrumphs a second time. There is another pause, and then David begins to speak (turn 040). He first talks about subtracting the death rate from the birthrate, then about adding the death rate, which is negative, to the birthrate, which yields "some positive . . . growth rate" (turn 040). (Signing quantities such as death rate negatively and adding them to other, positively signed quantities is an approach characteristic of the physics culture in which both the research assistant an the research participant are part.)

Fragment 7

```
034       (0.88)
035  D:   hhum
036       (0.43)
037  A:   round [this] region?
038  D:         [khmm]
039       (0.73)
040  D:   well, yeah, if you take, well shall i think i use the half if
          you take the birth minus the death (.) rate (0.63) `well the
          birth plus the death (.) rate which is negative, you are gonna
          get (0.13) some positive (0.98) growth rate; right?=
041  A:   =^yea ^[i=]m looking at the slopes of the curve[ss].
042  D:      <<p>[so]>                                  [uh]=<<p>okay.>
```

Following David's description of the general procedure, subtracting or adding the two rates to get their combined effect as the growth rate, Annemarie responds that she is "looking at the slopes of the curves" (turn 041). Here there is a contrast between David's description of the subtraction/addition of the two curves, which requires the subtraction/addition on a point-by-point fashion, Annemarie's utterance juxtaposes the consideration of slopes. In her utterance, the personal pronoun and verb, "I'm," are emphasized, setting what she has been doing in contrast with what David has been describing—if she had heard David say what she has been doing, she would not have needed to repeat it, even if in other words. David's subsequent production realizes the preceding utterance as a description different from what he has described, "uh okay," which can be heard as an "okay, I understand what you are doing." So in this situation, Annemarie explicitly points again to the fact that *she* is looking at the slopes rather than at the heights of the curves, and she is setting *her* approach against that which David describes—the one in which birthrates and death rates are added/subtracted. There is further evidence throughout the transcript that confirms Annemarie's continued focus on the slopes. Thus, as shown in Figure 10, there are repeated occasions where she holds the pen along the death rate curve, indicating its slope rather than the height at a particular position, where it has to be compared to the height of the birthrate curve. This comes dramatically to the fore in a subsequent instance further analyzed below.

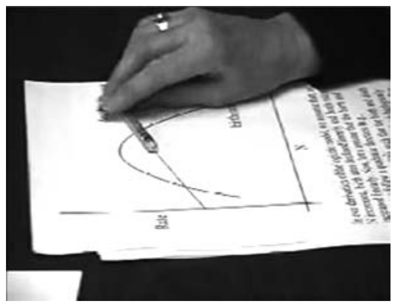

Figure 10. Annemarie repeatedly laid the pen parallel to the slope, showing and constituting her focus on the slopes all the while talking about heights of the curves.

In this situation, we also see how the think-aloud protocol has been changed to another type of situation in which the research assistant actually provides feedback when queried repeatedly, whereas feedback was to be given only after the session. But both research assistant and research participant collude to make the event emerge in this particular way. In fact, in the course of this part of the session concerning the population dynamics graph, Annemarie will continue to ask for feedback, as it becomes apparent that she struggles with making sense. Allowing the session to unfold in this way accommodates the participant and a possible loss of face in this encounter that places her opposite an undergraduate student from her own department, who apparently knows more about the graph than she does. Clearly, the change in situation from a pure think-aloud protocol without any clarifying query–answer sequence to one in which question–answers are accepted as part of the process is a decision achieved collectively requiring the collusion of both.[4]

From the point of view of the conversation, which is a *social* phenomenon sui generis, the utterances cannot be understood in terms of and reconstructed from the *independent* contributions of two speakers. Each utterance presupposes and waits for signs of the effect of the speech act in and from the mutual other *for whom* the utterance has been produced (Suchman, 1987). There is therefore an interlacing of utterances so that they can be

[4] In this particular instance, Annemarie and David eventually change the session into one where the latter comes to tutor the former in providing a standard correct reading. The analysis of the particulars of this tutoring session have been provided elsewhere (Roth & Middleton, 2006).

understood only as irreducible and mutually constitutive: Each utterance *implies* both the one it succeeds and the one that it precedes. That is, a conversation has to be modeled as a transactional phenomenon, where the contributions uttered by the participants are interdependent (Bakhtin, 1986). The *conversation* therefore constitutes the unit of analysis so that the utterance "Am I right then?" cannot be treated as a question until the next turn, which exhibits the effect part of the speech act as a whole. Cognition, expressed in conversation, therefore cannot be reduced to the individual but, inherently, implies shared consciousness and the sociality of cognition .

Some cognitive scientists may consider this situation to be a main problem for the field. But this is not so at all. Cognitive scientists with a social penchant, as any social psychologist, find their data not within "but entirely and completely *without*—in the word, the gesture, the act. There is nothing left unexpressed in it, nothing 'inner' about it—it is wholly on the outside, wholly brought out in exchanges, wholly taken up in material, above all in the material of the word" (Vološinov/Bakhtin, 1973, p. 19). Everything psychological exists and is learned in the real processes of communication and verbal interaction; and *society is in the mind* precisely because mind is materially found in society. Thus, we can read the transcript from turn 033 to turn 040 as a request for feedback, which, when it does not come forth, is further specified as to the exact location on the graph to which the query corresponds, before David's utterance reifies the utterance and its clarification as a question. That is, we can read the transaction as a persistent query and the initial reaction as hesitation; the persistence pays off, as David responds in an acquiescent manner. But this gloss is possible only from hindsight.

"Am I on the Right Track?": Further Evidence for Focusing on Slopes

The salience of the slopes in and to Annemarie's perception is further accentuated in Fragment 8, where she summarizes what happens to the population in the right part of the graph. Annemarie is in the process of summarizing the trend that as the birthrate is increasing *faster* than the death rate is increasing" (turns 110–114), "the population is in good shape" (turn 116). The production in this case is not quick, and Annemarie continues to pause frequently, as she has done throughout, in producing this summary. Her right hand moves the pencil tip along the birthrate curve as she articulates the salient feature, "increasing *faster* than the death rate is increasing" (Figure 11).

Fragment 8
```
106  A:   well it just—
107        (1.18)
108        feels that as long as the
109        (1.17)
110        um birthrate
111        (4.90)
112        IS INcreasing
113        (1.15)
114        fASter than the death rate is increasing
115        (1.23)
116        then the population is in (0.15) good ↑`shape. (0.86) but when
           the birthrate begins to decline
```

117 (1.98)
118 and the death rate stays the same ((pencil aligned with the death rate curve)) ((pause, pencil comes to left of intersection 2))
119 (3.55)
120 its okay for a while but eventually– clearly the ah (0.85) clearly the uh::
121 (1.14)
122 population is going to diminish. ↑am I on the right ˇtrack ((rH on paper near text))
123 (2.02)

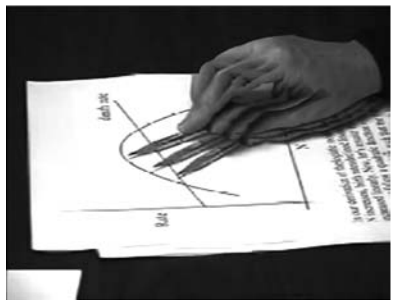

Figure 11. This overlay of three offprints shows the gesture produced simultaneously with the utterance “As long as the birthrate is increasing faster than the death rate, then the population is in good shape.”

This description of a population in good shape changes, however, as the pencil tip moves across the maximum of the birthrate curve (Figure 12a), a section that Annemarie articulates as one where “the birthrate begins to decline” (turn 116). There is a pause, followed by a statement that “the death rate stays the same” (turn 118). While she utters the description, she places the pencil parallel to the death rate graph (Figure 12b). As long (“for a while”) as the birthrate is above the death rate, “it’s okay” (turn 120), but when the birthrate lies below the death rate, then the “population is going to diminish” (turn 122).

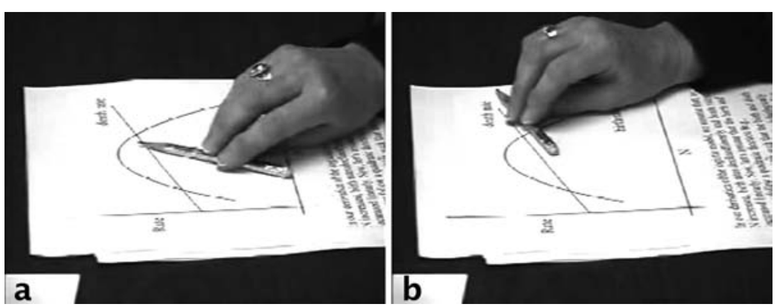

Figure 12. a. “When the birthrate begins to decline . . .” b. “And the death rate stays the same.”

In this situation, it is clear once again that Annemarie perceives and describes the slopes of the curves, which are the givens in her reasoning about what happens to the population of which the curves at hand constitute the birthrates and death rates. Annemarie is not just talking about the birthrate and death rate, but about the birthrate as “increasing faster” than the death rate in the area, as shown by her pencil, where both curves have positive slopes and the former being larger than the latter. She describes the situation to the right of the birthrate maximum as one in which “the birthrate begins to decline” (turn 116) while “the death rate stays the same” (turn 118). Here, clearly, going from the left to the right, the death rate increases for increasing *N*, whereas Annemarie perceives something that stays constant, something literally *aligned* with the pencil held closely to the death rate curve in the region that she currently talks about (Figure 12b).

In Annemarie’s talk, there is apparent a temporal dimension from left to right in the graph. That is, she does not take the graph to be a representation of birthrates and death rates as a function of the population (density). Thus, moving from left to right, she utters temporal terms: “as long as” (turn 108), “for a while” and “eventually” (turn 120), “begins to decline” (turn 116), and “is going to” (turn 122). Later in the session it becomes apparent that she treats the curves as if they were plotted against time so that going from left to right means a progression of the population in time rather than a plot of birthrate and death rate against the population (density). Neither here nor elsewhere in the session does Annemarie continue by suggesting that the population—when it is to the right of the right intersection point—would decrease and move toward the intersection point. Rather, as indicated here, the “population is going to diminish” (turn 122), which she later articulates as becoming extinguished. She also suggests that in this region, “your total number is going to be on a decline which will be difficult to recover from because the slop of this curve is quite steep at this point.”

Here again, as throughout the transcript, there is uncertainty apparent in Annemarie’s talk. She does not make definite statements but frames what she says for example as “it just feels that” and toward the end, she asks for feedback on whether she is “on the right track” (turn 123). There are also pauses and repetitions, such as from turn 119 to turn 122, where she both states that something is “clearly” the case all the while it takes repeated attempts to make the statement forthcoming. She is uncertain about what she has done and how it compares to the standard answer, which the research assistant is presupposed to know, as evident from the very fact that he is asked whether what she has said is right.

In summary, then, in contrast to the claims made in the literature about expertise, the scientists in this study generally, exemplified here by the data concerning Annemarie, were far from fluent in the production of their readings; and, more often than not, they made inferences and derived conclusions that professors and instructors of introductory level courses in physics and ecology would not have accepted as correct. Some readers may be tempted to claim that at least some of the participants in this project clearly were not experts. But this is contrary to those who claim (e.g., Linn, Layman, & Nachmias, 1987) that graphing is one of the core scientific process skills and that one would expect a scientists to be able to read a graph that students in introductory courses of their own discipline are expected to provide correct explanations of.

CORE PRACTITIONERS AND LIMITED NATURE OF EXPERTISE

This study was designed to investigate the nature of scientists’ graph interpretation expertise, especially the limits of this expertise related to graphs issuing from both within and outside their domain. A study concerning expert graphing in a leading cognitive science journal suggested that experts would be reading dynamic equilibrium graphs such as the one presented here or those in economics (Figure 13) in the following way.

> This [supply and demand line] has been stored in the expert's mental image (visual buffer). . . . The expert wishes to explain why the price, if it were currently above the equilibrium price, would be driven down to that price. He does this by considering (in a pictorial representation) a higher price, showing that at this price there would be a surplus (greater supply than demand), and then reasons verbally that the price would decline. Thus, he uses both pictorial and verbal representations in this explanation. (Tabachneck-Schijf et al., 2007, p. 321)

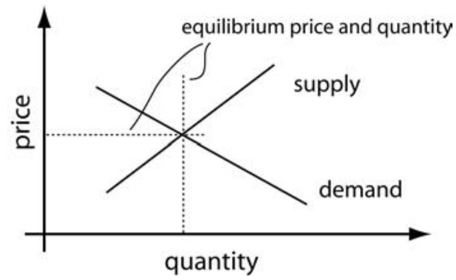

Figure 13. Fundamental laws in microeconomics that relate producer supply and consumer demand are of the same dynamic nature as birthrates and death rates are for populations.

The present study shows that with respect to the graph featuring the two dynamic equilibriums, 47% and 41% of the physicists have been able to identify the unstable and stable equilibriums, respectively, in the in-field graph situation; in the out-of-field situation, the rates were 29% and 35%. Although the reasons varied across individuals, the physicists generally did not talk about the graphs as dynamic situations in the way that the economist did in the Tabachneck-Schijf et al. study. More so, the physicists in the present study, in the same way as the ecologists in a previous study (Roth & Bowen, 2003), analyzed the dynamics in terms of difference in the two curves to the left and right (horizontally above and below) of the intersection point; whereas the economist expert compared the two curves vertically above and below the intersection point. It is evident that their inferences came from perceptions that are different than those postulated for experts in the cited study. And the perceptions are in part driven by the cultural expectations rather than by some form of raw perception taking in by the eye that acts like a *camera*. More so, as the detailed example of Annemarie shows, there is no evidence for any of the processes described to occur in the CaMeRa model, including as to what is being stored in mind and what is not. Thus, for example, whenever this study shows that whenever Annemarie needed to access visual information, she oriented toward the required aspect. Even when she was merely indexing a part of the graph, she did not do so mentally—there is no sign even in my second-to-second and frame-by-frame approach—but physically, keeping her pencil right on the feature that she kept track of. Rather than stating that the population (*N*) would decline in the region of the graph where death rate curve lies above the birthrate curve and then moves left to the next equilibrium point, those physicists who did not produce the standard correct answers took the graph as implying a crash of the population. Whereas this is the case for the left equilibrium, we need to be cautious with our interpretation about the actual model that the participants expressed. Thus, to the left of the lower equilibrium, the dynamic and the static model lead to the same implication: the population crashes. To the right of the right equilibrium, however, the population declines but only until it reaches the equilibrium (to which, if it overshoots, it will return). However, the scientists who did not infer the equilibrium generally stated that the population, once in this region, would crash. That is, many scientists in this study did not see the intersections as equilibrium points whereas this is the starting point for the CaMeRa model.

The graph reading expertise of scientists is limited even within their field but, in some instances, even more so when scientists are asked to interpret graphs from outside their field. In this study, scientists interpreted in-field and out-of-field graphs in an experimental setting rather than at work. This type of setting is regularly used in studies where scientists serve as an expert reference group to be compared with novices. Experts not only are assumed to be capable of successfully completing tasks in their own domain but also to have a capacity for transferring skills between domains. (For a critique of the assumption that experts transfer, see Lave [1988].) The present study does not support the notions (a) that graph reading/interpreting is a general scientific process skill and (b) that experts (easily) transfer skills to other fields. Interestingly, however, this study may lend support to another one conducted in the discipline of petroleum science where novices, intermediate experts, and full experts were asked to interpret images of rocks (Abel et al., 2005). In that study, there was gap between the explanations experts gave when explaining their discipline and what they said when making decisions in their discipline. When they described rocks or explain their discipline, they appeared to employ precise vocabulary, whereas they were not able to articulate even semi-formal justifications for their interpretations of petrographic representations. Although the present study did not ask the experts to explain their domains, there, too, appeared to be a gap between what the physicists teach in their courses and what they expect their students to know, on the one hand, and the explanations that they provided when working on tasks taken from undergraduate courses, on the other hand. However, such an interpretation would run counter to that provided in my previous study, where university scientists who also taught undergraduates by far outperformed equally prepared non-university scientists.

The physicists' interpretive practices in this study were far from those that one would expect experts to exhibit, as my participants frequently provided no more than literal readings and failed to perform standard interpretive practices even on in-field graphing tasks but especially on out-of field graphing tasks. We are confronted with these results despite the following aspects that should have made it easy for them to produce standard (correct) interpretations. First, the graphs in this study are similar to those that one can find in typical undergraduate courses of physics and ecology. Second, each pair of physics and ecology graphs has structural similarities in their surface and deep structure, a fact that should have facilitated transfer. This study shows that graphing (graph interpretation) cannot be assumed to be a general scientific process. Rather, it is a social practice employed for achieving specific purposes in particular contexts. My work shows that the scientists exhibited somewhat greater ease with in-field graphs than with the out-of-field graphs.

This study exhibits the contingent nature of graph interpretation even among those who might be considered to be experts with respect to core procedural knowledge in the science. This contingent nature of graph interpretation exists for both in-field and out-of-field graphs. We also find that the points or features in a graph that become salient cannot be determined a priori but rather emerge from the context of the task. For example, in dynamics graph interpretation, almost all of them (15 in biology dynamics graph and 14 in physics dynamics graph) mentioned the intersections. On the other hand, in the distribution graph interpretation, none of them attended to the intersections, although there were many intersections between the different plant and electron distribution graphs. The flow of the focus changes of their interpretation differed from person to person within a task, which also made evident the contingent nature of their interpretation practice. The function of the ongoing purpose, which is a determinant of a social practice, appears to be common across domains.

When participants interpreted a graph, they drew on available material resources, including axis labels, units, and scales. This study shows, however, that we do not know a priori which of these resources any individual scientist will be drawing on, and, as the case of Annemarie showed, two aspects might be interfering. We therefore need to conduct our studies concerning expertise very carefully, making sure that we ascertain what the actual structures are that are salient to the participant, which in some instances may actually involve contradictory uses of one and the same resource. There were differences between in-field and out-of-field graphing tasks; more questioning and variations of interpretation occurs in out-of-field than in-field graph while they access these material resources. For example, the physicists spontaneously revealed their background knowledge related to the axis labels in the physics distribution graph (e.g., Bohr radius, distance from the nucleus), even though these are not mentioned in the graph or caption. None of them asked about what the axis label “x” is in physics dynamics graph, but in population dynamics graph, many of them asked about the meaning of “*N*”—despite the fact that scientists universally use this label to indicate (relative, absolute) number of cases.

When physicists worked on in-field and out-of-field graphing tasks, they used various resources in their interpretation. In our database, we find considerable differences in the use of linguistic resources between the two fields. This leads to the differences in the extent to which background knowledge is articulated, and in the precision of the knowledge that is rallied in the interpretation. For the out-of-field graphs, physics experts drew more on experience from everyday life or on common sense, whereas in-field graph interpretations more experience from their professional work was used. Many of the out-of field graph interpretations were limited to literal readings, which participants frequently explained in terms of their lack of background knowledge, and participants confronted breakdown more frequently in out-of-field than in in-field graph interpretations. This result can be thought of as showing that graph interpretation practice reflects familiarity with the world referenced. This finding is consistent with the claim that interpretation does not get information *out of the graph*, but that graphs constitute occasions for the concrete articulation of knowledge of familiar worlds (Roth, 2004). In this sense, success in interpreting graphs is a function of familiarity with the referenced world and of the degree to which the individual establishes a link between representation and world. If individuals are unfamiliar with some graph, they tend to seek connections with their everyday life world and experiences. Graph interpretations then are characterized by common sense and everyday language.

In summary, therefore, practicing scientists’ expertise with respect to reading graphs appears to be more limited than generally thought. More so, the skills that scientists generally exhibit when it comes to familiar graphs—e.g., from their own work or work in their area of research or teaching—is not transferred to introductory-level graphs even if these are from their own domains. Again, the results of this study point to a more limited nature of expertise, which likely is linked to the levels of familiarity with the specific representations and the contextual particulars in which they appear.

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APPENDIX
TRANSCRIPTION CONVENTIONS

In this chapter, I draw on transcription conventions common to conversation analysis enhanced by transcription features specific for researchers interested in marking prosody (Selting et al., 1998). I added specific features for transcriptions that include video offprints. The transcription is neither grammatical—see punctuation—nor consistent with spelling rules but attempts to exhibit the sounds as produced.

Feature in context	*Explication*
(0.25)	Time in hundreds of seconds
(.)	Pause less than 0.10 seconds
((draws line))	Double brackets surround transcriber comments.
hh, uh	Outbreath, each "h" corresponding to 0.1 seconds.
survi:ve	Colon indicates lengthening of phoneme, each colon corresponding to 0.1 seconds.
r=one	Equal sign means "run-in" of the phonemes or "latching" of different speakers, meaning no pause between phonemes.
084 <<p>point [he:re] 085 [than with]	Square brackets in consecutive turns indicate extent of overlapping speech, features.
;.,?	Punctuation marks indicate movement of pitch toward end of utterance segment, down, strongly down, up, and strongly up, respectively
<<p>point>	Triangular brackets mark prosodic features, here "piano," that is, lower than normal intensity.
<<pp>point>	"Pianissimo," much lower than normal speech intensity, next to inaudible intensity.
<<dim>point>	"Diminuendo," decreasing speech intensity.
<<all>first>	"Allegro," fast.
<<h>that's>	Higher than normal pitch register.
[, $[_2$	The bracket marks the coincidence of an offprint (part thereof) with the transcription of words.
↑↓`b ‘clear	Arrows and diacritics indicate movement of pitch: upward and downward jump, downward and upward contour of phonemes that follow.
OR	Capital letters indicate louder than normal speech.