THE NATURE OF THE BOUNDARY CROSSING BETWEEN IN-FIELD AND OUT-OF-FIELD IN SCIENTISTS’ GRAPH INTERPRETATION PRACTICE

Scientists are expected as having an exemplary expert in graphing because graph-related practices are central to scientific enterprise. Graph interpretation is very pervasive practice in scientific researches and also in science learning. When scientists interpret graphs from out-of-fields, there is a kind of boundary crossing compared with interpreting graphs from in-fields. The purpose of this study is to investigate the nature of the boundary crossing between in-field and out-of-field in the scientists’ interpretation of graphs from out-of-fields and in-fields. Physicists (N = 17) interpreted three biology graphs, and then three physics graphs, which have similar structures in pair. The interpretations were performed in a think-aloud interview. All interpretive activities were analyzed using discourse analysis and interaction analysis. From the analyses, we could identify three types of boundary crossings in their graph interpretations; smooth transitions, boundary crossings managed, difficult transitions. Not only the background knowledge, but also emotions played important roles in scientists’ boundary crossing between in-field and out-of-field.

Implications for graph-related education in school science are made

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Introduction

Graph-related practices are central to professional science. For professional scientists, interpreting graphical representation from their own researches as well as from others’ plays an important rhetorical role in scientific communication. For the students of science, many graphs in their textbooks, and sometimes the graphs from their own experiments or from peers’ are required to be interpreted by them. In most of the expert-novice researches (e.g. Larkin, McDermott, Simon, & Simon, 1980; Savelsbergh, De Jong, Fergerson-Hessler, 2002), scientists are assumed as experts compared with students (or novices), but scientists as experts are often intimately familiar with the domain of task. According to the previous researches about scientists’ graph interpretation (Roth & Bowen, 2001, 2003; Roth, 2003), there was a great difference in their interpreting practice according as the graphs were from their own work or not. They read or interpreted the graphs from their own work with lots of contextual details, but many of them could not produce a standard interpretation of the graphs from undergraduate textbook in their own field. That result requires a new model of graph interpretation, and two-stage model was presented to explain the scientists’ graph interpretation (Roth & Bowen, 2001). But the research was only about the graphs in their own field, whether it is from their own work or from undergraduate textbook. From the larger research agenda of
understanding graphing expertise, the next step was scientists’ interpretation of graphs from out-of-field. If we understand better how scientists interpret graphs from out-of-fields compared with interpreting structurally similar graphs from their own fields, there are important implications for teaching students graphing expertise.

This study focused on the scientists’ graph interpretation practice when the graphs from in-fields and out-of-fields are given by the investigator. The purpose of this study is to investigate the nature of the boundary crossing between in-field and out-of-field in the scientists’ interpretation of graphs from in-fields and out-of-fields. How scientists deal with the unfamiliarity when they cross the boundary in their out-of-field graph interpretation can provide significant suggestions for teaching students graphing expertise, who are confronting rather unfamiliar graphs throughout their science learning process.

**Theoretical Framework**

**Graphing in Science: From Cognitive Ability to Social Practice**

Many of the ethnographic works of scientific laboratories and scientific field work indicated that graphing is quintessential scientific practices (Latour & Woolgar, 1979; Lynch, 1985; Latour, 1987). Scientists are usually considered as experts in graphing and are assumed to have graphing expertise in many graph-related researches (e.g. Tabachneck-Schiif et al., 1997; Kaupt, 2000). Contrary to the scientists, research literatures on graphing show that students of all ages experience difficulties when they are asked to produce or interpret graphs (Berg & Phillips, 1994; Leinhardt, et al., 1990). The students’ difficulties in graph-related practices have been attributed to misconceptions (Leinhardt et al., 1990), cognitive deficits (Berg & Pillips, 1994), other more generic deficiencies (Preece & Janvier, 1992), and more recently, students’ alternative conceptions (Mevarech & Kramarski, 1997; Kramarski, 2004). These researches explained that difficulties in graphing are related to students’ cognitive abilities or mental structures.

Recent studies on graphical representations, more appropriate term inscriptions in the literature on the sociology of scientific knowledge, revealed that graphing can not be explained solely by cognitive abilities, rather it should be interpreted by using a new theoretical framework of social practice (Roth & McGinn, 1997; 1998; Roth, Bowen, & McGinn, 1999). Graphs, as one kind of inscriptions that are used across several communities of practice are referred to boundary objects (Fujimura, 1992; Henderson, 1991). Boundary objects are inscriptions used across space and time, and by people from different social worlds. In this study, the graphs from in-fields (physics) and out-of-fields (ecology) can be thought as boundary objects, which serve as topic of and as background to conversations; they allow the translation, coordination, and articulation of different, community-specific material and discursive practices (Roth & McGinn, 1998).
Scientists were asked to provide graph interpretation as an expert in a think-aloud interview session. The graphs given to them were three biology graphs and then three physics graphs, which had structural similarity. When they interpret the out-of-field graph, they cross the boundary between in-field and out-of-field. While they return to interpret their own field graph from out-of-field graph, they cross the boundary again. The setting was experimental in that the tasks were given by the researcher, but we tried to articulate the nature of the boundary crossing between in-field and out-of-field in scientists’ graph interpretation practice in anthropological perspectives.

Why is Boundary Crossing Important?

The concept of boundary crossing has been used to express students’ multiple worlds of learning (Phelan et als., 1991) or learning science in cultural perspectives (Costa, 1995; Aikenhead, 1996; Aikenhead & Jegede, 1999; Krogh & Thomsen, 2005) to expand the concept of learning including cultural aspects. In vocational education, boundary crossing between school and work were used as a tool for promoting learning and transfer (Tuomi-Gröhn & Engeström, 2003; Tuomi-Gröhn, Engeström, & Young, 2003). These studies are focused on the learner’s boundary crossing between multiple worlds of learning. There are some researches about the boundary crossing in interdisciplinary studies of scientists (Palmer, 1999; Pierce, 1999) and emphasizes that the boundary crossing has become a defining characteristic of the age (Klein, 1996). Although boundary crossing is very commonplace phenomena in today’s knowledge world, the researches about cognitive process of scientists’ boundary crossing has little been studied.

In this study, we focused on the boundary crossing between in-field and out-of-field in scientists’ graph interpretation practice. The interpretations of graphs from other scientists’ researches in their own fields and even from other fields are pervasive practice for scientists today. The similar kind of practical activity, the interpretation of unfamiliar graphs can also happen while students are learning science.

Using cognitive anthropology of graphing, we tried to articulate the nature of the boundary crossing between in-field and out-of-field in the scientists’ graph interpretation practice. When the scientists interpret the graphs from out-of-fields, they cross the boundary into other domains of science. In this rather unfamiliar situation for the scientists, what scientists are doing to interpret graphs from out-of-fields was analyzed using discourse analysis and interaction analysis. Instead of using the term of transfer, which confine the meaning of knowledge as something that exist in the brain and carried by the subjects at every other contexts, we chose the concept of boundary crossing to describe the whole practical aspects of interpretation in a social context. Boundary crossing presupposes the existence of boundary or border between two different worlds or territories, and emphasizes the dynamic aspects of transiting between multiple worlds. In this study, the graphs as boundary objects, mediate the different worlds of physicists and ecologists. We focused on the scientists’ interpretation practice in the out-of-field graph interpretation in that they interpret them across the boundaries of their own work.

Model of boundary crossing in scientists’ graph interpretation
In the previous studies of scientists’ graph interpretation, semiotic model was presented to explain the graph interpretation as a semiotic process (Roth & Bowen, 1999; Roth & Bowen, 2001, 2003; Roth, 2003). The model assumes that the lines making graphs and all additional textual information constitute text. These texts are therefore a network of signs that readers have to perceive in such a way that it allows them to reconstruct a consistent and coherent narrative of a situation that a graph can be said to describe. Thus, reading and interpreting graphs are concerned with texts (signs, denoted by S in the model) and with the entities that these texts are said to signify (referent, denoted by R in the model). Each individual is understood as being engaged in a process of semiosis, identifying signs and establishing sign-referent relations by elaborating interpretants. Each verbal or graphical production by scientists therefore pertained to establishing a four-parameter relation linking the content (referent), on the one hand with sign in its context given the rules that the embedding scientific community of practice imposes on such relations (Roth & Bowen, 2001; Roth & Bowen, 2003). If we apply the semiotic model to explain the boundary crossing in this study, we can describe the interpretation process as the two-fold model of graph interpretation in Fig. 1.

![Fig. 1. Two-fold model of graph interpretation between in-fields and out-of-fields](image)

On each side of the boundary between in-fields and out-of-fields, there are two models on each side. The signs can be seen as identical because they have the structural similarity in their graphical components and caption sentence structures. But, the contexts of each sign, rules, and therefore the contents of the interpretation are different between in-field and out-of-field graph. They are denoted by (i) and (o) in the model respectively.

When they interpret the out-of-field graph, they encounter the unfamiliarity with the context of the graph and the difference in the rules that are controlling the interpretation of out-of-fields graph. They tried to search links from their familiar world, in-field in order to give plausible interpretation. Their boundary crossing actions were analyzed in three aspects, the cognitive aspects, the affective aspects, and the confirmation of their identities. We could identify three types of boundary crossings according to their relative competence to interpret out-of-field graphs. The first type is smooth transitions in which they can interpret the out-of-field graph successfully in providing standard answer without much difficulty. In these cases, they can have the necessary background knowledge to produce meaningful interpretation at ease. The second type is boundary crossing managed, in which they have some reluctance in the out-of-field graph interpretation but managed to interpret it. In these cases, their recovery in their feeling from frustration to relative ease is parallel to their cognitive interpretive practice. The third type is difficult transition in which they experienced difficulties in out-of-field
graph interpretation. In some cases they would not try to cross the boundaries and just wanted to stay in their own territory.

Methodology

Participants

17 physicists were asked to interpret three biology graphs and then three physics graphs in an interview session using think aloud protocol. They were mainly professors including one post-doc and three doctoral students. There were 15 men and two women. 14 had obtained a Ph.D. degree between 0 to 42 years prior to our interviews (X = 19.5, SD = 15.6 years). All had a minimum six years of experience in doing independent research. All but one research associate were involved in teaching graduate, undergraduate, or laboratory courses in physics and physics-related departments. An undergraduate research assistant as part of a work term in his cooperative program in physics conducted the interviews with the physicists.

The Task Design

Three biology graphs that had been used previous studies (Roth & Bowen, 2001; 2003) and three physics graphs that were prepared with a similar method as the analogues of the three biology graphs in both caption and physical appearance were very typical ones in undergraduate course in each subject.

The first graph pair was distribution graph; physics graph was a different distribution of electron charges in four s-shells taken from a quantum mechanics textbook and the biology distribution graph, the three different types of plant distribution showing the differential adaptations to environmental conditions. The caption attached on each graph provides the participants with the associated situation. The task was formulated in a caption such that the participants were instructed to talk about the implications that could be drawn from the graph. This graph pair including captions was shown in Fig. 2 as an example.

The second graph pair was dynamics graph; the physics dynamics graph constitutes the model of dynamical system of an object and the two opposite directional forces acting on it from classical mechanics and the biology dynamics graph constitutes the model of the density dependent population in which the two lines represent birthrate and death rate. In these tasks, participants were specifically asked to focus on the two intersections and the resulting three sections along the abscissa. The correct interpretation identifies the two intersections as an unstable and a stable equilibrium, respectively in each graph.

The third graph pair was isoclines graph; physics graph was three contour plots from thermodynamics and the three biology isoclines graphs represent essential, substitutable and complementary resources, respectively. In each of the isoclines graph, two independent variables are related to a third, dependent variable, which is represented in the forms of isoclines, lines of equal effect.
Finally, the three selected graph pairs differed in type and complexity. They were presented to the physicists in an interview context to be interpreted in the order of three biology graphs, distribution, population dynamics, isoclines graph and then, three physics graphs, the same order as in biology graphs.

**G1. Biology Distribution Graph**

![Distribution Graph](image)

Distribution of C_3, C_4 and CAM (crassulacean acid metabolism) plants in the desert and semi-desert vegetation of Big Bend National Park, Texas, along a moisture and temperature gradient due to differences in elevation. CAM plants with nocturnal gas exchange for water conservation predominate in the hottest, driest environment. C_4 plants are maximally important under intermediate temperature and moisture conditions, and C_3 plants predominate at the cooler, least dry end of the gradient (after data of W.F. Botsford, 1978, Photosynthesis, 12, 291-297). What implications can you draw from this graph?

**G4. Physics Distribution Graph**

![Distribution Graph](image)

Distributions of electron charges in K, L, M, and N s-shells for hydrogen-like atoms along a relative radius continuum or succession. Distribution K has a maximum near relative radius 1.0, L near 1.5, M near 12, and N near 25 relative radii. What implications can you draw from this graph?

**Fig. 2. Distribution Graph Pair. G1, Biology Distribution Graph: the different distributions of three types of plants is used to make inferences about the differential adaptation to environmental conditions, here climate. G4, Physics Distribution Graph: the different distributions of electron charges in four shells are used to make inferences about the differential ionization energies for each shell. The graphs were numbered by the order of being presented to the physicists.**

**Data Collection and Analysis**

The physicists were asked to participate in a graph interpretation session for the purpose of providing expert answers for the selected same six graphs in an interview context. The interviews were all conducted in the principal investigator's research laboratory and videotaped. Prior to the graphing sessions, a brief structured interview to establish
biographical background information was conducted. They were instructed to make as many inferences as possible for each of the graphs and think aloud. We had prepared a standard set of pre-formed questions/prompters for the physicists so they would continuously interpret the graphs, but the interviews were conducted according to the contexts. They were instructed to indicate when they considered to be done and had nothing more to say. The sessions lasted between about thirty and one hundred minutes.

The three biology graphs in the order of distribution, dynamics and isoclines graph, and three physics graphs in the same order were given to the scientists. All the interviews were videotaped and transcribed. The digitalized videotapes, transcripts, and the artifacts, which were made by the physicists during the interviews were constituted texts, were analyzed using discourse analysis (Edwards & Potter, 1992; Potter, 2004) and interaction analysis (Jordan & Henderson, 1995). All the transcripts were read and coded independently by each author and parts of relevance to the research topic were annotated and made assertions. For each assertion, we reviewed other episodes throughout the whole database to check the degree to which they confirmed or disconfirmed it. On the basis of these checks, we formulated initial assertions until they were representative of the data.

Results

Boundary crossing is pervasive in many of the interdisciplinary activities. In this study, we tried to articulate the nature of boundary crossing practice between in-field and out-of-field in the physicists’ biology graph interpretation compared with the structurally similar physics graph interpretation. We could identify three types of boundary crossings according to the relative competence to interpret out-of-field graphs; smooth transition, boundary crossing managed, and difficult transition. When we classified the physicists’ out-of-field graph interpretation according to the boundary crossing types, there were some difficulties in deciding to what type of boundary crossing each graph interpretation session belongs. Because there were changes of types even in a graph interpretation when the interpretation was unfolding with time, we had to judge from the whole interpretation as well as some important aspects we had concerned with. Table 1 shows the case numbers of boundary crossing type in each graph interpretation.

<table>
<thead>
<tr>
<th></th>
<th>Smooth Transition</th>
<th>Boundary Crossing Managed</th>
<th>Difficult Transition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution</td>
<td>1(6%)</td>
<td>1(6%)</td>
<td>15(88%)</td>
</tr>
<tr>
<td>Dynamics</td>
<td>4(24%)</td>
<td>4(24%)</td>
<td>9(53%)</td>
</tr>
<tr>
<td>Isoclines</td>
<td>1(6%)</td>
<td>4(24%)</td>
<td>12(71%)</td>
</tr>
<tr>
<td>Total</td>
<td>6(12%)</td>
<td>9(18%)</td>
<td>36(71%)</td>
</tr>
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</table>

Table 1. Case numbers of boundary crossing type in each graph interpretation
The results show that the numbers of each boundary crossing type are different from graph to graph. It means that the boundary crossing appeared different according to the given tasks. We present the typical cases of each type and the conditions of each type of boundary crossings can occur. To get the implications to teach students graphing competence, the detailed analysis of the reasons of difficult transition can provide more insights as well as the conditions of smooth transition and the barriers of managed boundary crossings.

In their graph interpretation across the boundaries of in-field and out-of-field, availability of knowledge necessary to provide standard interpretation and their feeling at ease played important role. In some instances, their identity expression such as non-biologist made them a step backward in their interpretation and made the boundary crossing difficult.

Smooth Transition: No Apparent Boundary

The first type of boundary crossing is smooth transitions in which they can interpret the out-of-field graph successfully in providing standard answer without much difficulty. In this type of boundary crossing, the scientists interpret the graphs as if there were no boundary at all. They knew what are to be described in each graph and used the necessary tools at ease. We present a typical example of smooth transition in the following excerpt.

P16: Well, the first, the first thing to note is if you are below this first cross over point, I’m, you’re clearly at a, in an unstable situation. For whatever reason that argue if the population, that if the density is low you have trouble finding mates for the world, the death rate, the birth rate is low. In any case what ends a patterning is that if you happen to be in this regime right here, the death rate is higher than the birthrate. The population will decrease. And you’d be driven down towards lower, and, and that trend continues so that looks like uh, an extinction, sorry situation. Um, within this region regime right here, um, where you are on, uh, above the second intersection point, uh, there is a stability one would get driven towards this intersection point.....(P16 in biology dynamics graph interpretation)

In this case, the physicists know what to say first, the most important concept of the stability of the population in each region, which did not appear in the graph and caption. He could explain the change of population with plausible reasoning from the information in the graph and caption and from his common sense of ecology. From the comparison of the relative magnitude of death rate and birthrate, he could predict in what direction the population will change, and he could assess the state of the population such as sorry situation. His interpretation continued in other regions and talked about the stability and the direction of population change. He covered all the important aspects in the interpretation of a given graph and all these interpretive practices were performed without any great difficulties.

Another example of smooth transition shows that knowing what to say and using the necessary tool to interpret the out-of-field graph easily. P08 grasps the meanings of the signs while he was reading the caption in biology isoclines graph. The following is the
part of his reading caption, and the utterances that are not on the caption were transcribed.

\[ P08: \text{So, um, let's see. .....three graphs here, um, } R2 \text{ versus } R1 \text{ and different contours, .....that's } R, \text{ so } R1 \text{ and } R2 \text{ must be different types of nutrients.} ..... \text{So 20, 50 and 100, I guess, are somehow quantifying the amount of plant growth. 100 presumably weighs more than, is the greatest growth. (P08 in biology isoclines graph interpretation)} \]

While he was reading down the caption lines, he expressed his understandings of what the variables on each axis and the numbers on the contour lines mean. So, he could continue to interpret the three different scenarios without any hesitation or difficulty beginning with (a) and comparing the others with the previously explained scenarios. He paid his attention the fact that there are no units on the axes, and he considered that in interpreting all the three scenarios.

Another important feature that made him the boundary crossing smooth was using his own tools to interpret the out-of-field graph. The tool was adding lines on the graph and he could have concrete salient points on the graph to explain the relationship between \( R1 \), \( R2 \) and the growth rate. The following figure (Fig. 3) and corresponding transcripts show how he used his tool at his ease.

\[ \text{Fig.3. The drawings added by P08 during his interpretation of biology isoclines graph (a)} \]

\[ P08: \text{...but in any case, the proportion of } R1 \text{ and } R2 \text{ is fixed along a diagonal line and it appears that the, the uh, growth is maximized when } R1 \text{ and } R2 \text{ are in that proportion. Um, if you change the proportion, you're effectively ((draws diagonal line)) going ((draws a line with lower slope than diagonal)) at a different slope in this graph and then uh, for a given amount of } R1, \text{ you get a lower, uh, a lower growth rate. And similar rate ((draws a line with higher slope)) have us graph here, so again for } a, \text{ a given amount of } R2, \text{ in that case, you would get a lower growth rate. Um, so, in some sense uh, you would, a, a} \]
reasonable conjecture, would be that, in order to utilize one of these nutrients, you need at least a certain amount of the other if you get an excess amount of the other, then uh, that does you, does you little good. (P08 in biology isoclines graph interpretation)

He drew similar lines or curves and used some salient points in his drawing to interpret (b) and (c) in biology isoclines graph. Using his drawings that are consisted with added lines and curves, he compared the differences between (a), (b), and (c), and explained successfully the concepts of essential, substitutable, and complementary resources, although not to the extent to use exact terminology.

In smooth transition type of boundary crossing, the scientists can identify all elements in the set content, sign, context, rules and relate them in an appropriate way in the out-of-fields graph interpretation across the boundary between in-field and out-of-field. They knew what to say in a given new context according to the rules although not explicitly talked about that. They also found the links to the out-of-field graphs from their experiences of in-field in using tools necessary to interpret the out-of-field graphs. So, the boundary that lies between in-field and out-of-field has disappeared in this type of boundary crossing.

Boundary Crossing Managed: Overcome the Emotional Barrier

In the second type of boundary crossing, the physicists managed to interpret the out-of-field graphs with some difficulties, and finally overcame the barriers coming from unfamiliarity. The unfamiliarity of out-of-field gave them the reluctance to interpret the graph across boundary into out-of-field. In such cases, the interaction with the interviewer played important role to elicit the appropriate interpretation. Identity confirmation such as ‘I’m a physicist, not a biologist,’ was often expressed when they met some kind of difficulties during their interpretation, and made them a step backward to interpret the unfamiliar out-of-field graphs.

P04: ....NO, I'm afraid I have to say that graph means nothing to me at all. And I just don’t know what it means. Um, ((pause, 9sec, 02:10)) I'm sorry I'm drawing a complete blank [and I-]....

Interviewer: [Um,]

P04: I don't know what it means at all.

Interviewer: Can you um, try and explain what ((02:15)) you’re doing to try and even understand the graph? ((pause, 5sec, 02:24)) like a-

P04: Well, I assume that you are plotting something against something. You are plotting the amount of the nutrient one against the amount of the nutrient two, uh, what are the capital A, and B, and C?

.......................................................... ..........................................................

P04: if you got so much of nutrient 2, huh((laugh)) if you got so, okay, if you got so much of nutrient 2, then the plant, ((pause, 8sec, 05:27)) oh, I see, oh, uh, uh, hah((sighs)), then the plant would grow at a rate of 50, regardless of how much R, nutrient 1 is present. And if it's got so much of nutrient 1, the plant will grow at rate 50, regardless of how much of R2 there is. So it needs a
minimum of so much of R1 or so much of R2, independently what the other one is. I don't know that’s right or not. ...(P04 in biology isoclines graph interpretation)

This physicist started his interpretation with embarrassment as uttering “Oh, my goodness, well, oh,” and expressed difficulties repeatedly while he attempted to interpret the graphs. According to the interviewer’s interactive suggestion, after re-reading the caption, he managed to interpret the graphs even to the idea of “essentiality” and “substitutability” of the two nutrients. After finishing interpretations, he showed the humor asking the interviewer if he could pass a degree in botany. Although he responded negatively to the interviewer’s positive answer, his emotion recovered from the frustration in the beginning state.

In some cases of this type of boundary crossing, the scientists showed the uncertainty of their interpretation, and asked repeatedly if their interpretation was right (e.g. P06 and P13 in biology dynamics graph). When they found some discrepancy with their knowledge or experience in the graph and caption, they asked about the unclear points until everything became clear (P05 in biology isoclines graph). In these cases, the interaction between the interviewer and the scientists played an important role to get the managed boundary crossing.

To think about this type of boundary crossing in terms of our two-fold model, the scientists feel some kind of negative emotions such as embarrassment or frustration when they confronted the unfamiliarity of the contexts or sometimes the text itself. When they try to find the rules that go across the boundary between in-field and out-of-field, they come to know there are some inconsistency between their knowledge and experience and the signs to be interpreted. These two kinds of difficulties prevented them cross the boundary and produce a meaningful interpretation. With the interactive question and answering with the interviewer was very helpful to make their boundary crossing managed.

**Difficult Transition: Confronting Unfamiliarity without Meaningful Interpretation**

The third type of boundary crossing is difficult transition in which they experienced difficulties in out-of-field graph interpretation.

*P01: Oh, Big Bend … Texas, Okay. Hugh, pitsu, pitsu, tsu..((sighs and pause, 11sec))*

*P01: Okay, so now what uh, implications ((sighs)) can I draw from this graph? OK, implications to what?*

*Interviewer: Well,*

*P01: Like what should I look for?((05:52))*

*(P01 in biology distribution graph interpretation)*

The first line of this excerpt was the beginning utterance and the rest of it is the last part before the interviewer asked the prompting questions. In this case, the physicist expressed
the lack of understanding of the graph several times and could not give a meaningful interpretation of the graph. This scientist could remain only within the graph.

There are some cases similar to this case. When they know the fact that they do not know the necessary background knowledge, their interpretation of out-of-field graph could not go beyond the boundary between in-field and out-of-field (P03 in biology distribution graph). They re-identify themselves according to the given task, as non-biologist, or even a layman and admit there were some professionals to deal with the task (P04 in biology distribution graph). In those cases, they would not try to cross the boundaries with reluctance and just wanted to stay in their own territory saying that lack of information or inadequacy of the graph.

There are cases although they are familiar to the shape of the graph from their experience in their field, they could not provide any meaningful interpretation of out-of-field graph because they are not familiar with the context behind the graph and do not know what the graph really means. This means the importance of context in graphing in science.

In this type of boundary crossing, the unfamiliarity with the sign itself, the context behind the sign, and the community-specific rules together made the boundary crossing difficult.

**Discussion and Implications**

From the analyses about the physicists’ interpretation of out-of-field graphs, we could articulate how the boundary crossing between in-field and out-of-field could occur in the graph interpretation practice. In all three types of boundary crossing, the graph interpretation practices across the boundary between in-field and out-of-field are always related not only the cognitive aspects but also the affective aspects.

In the smooth transition, they can cross the boundary between in-field and out-of-field without explicit expression of difficulties. Their interpretation proceeded to the out-of-fields if there were no boundaries at all. They can use the necessary knowledge to interpret the graph from the caption and the graph itself, their common sense, and their previous experiences related with the graph in general and some of them enjoyed the process of boundary crossing. In boundary crossing managed, they had some kind of difficulties and expressed negative emotions such as frustrations or embarrassment from the unfamiliarity of the out-of-field graphs. But finally they overcame the difficulties through the responsive interaction with the interviewer, managed to interpret the graph, and recovered from the negative emotions. In difficult transitions, the lack of necessary knowledge to interpret the graph and the unfamiliarity made the physicists difficult to produce any meaningful interpretation.

From this result, we can get important implications for teaching graph interpretation in school science education. For the students in school, they do not have their own fields. This means almost all the graphs that students can be met in their process of learning science are like the out-of-field graphs for scientists. For the smooth transition into the unfamiliar graph from familiar graph interpretation, the learning of the necessary knowledge through a direct experience dealing with the data within a real context is
necessary. The social interaction between peers or with teacher is important to boundary crossing into the unfamiliar out-of-field graph from familiar in-field graph interpretation to overcome the difficulties to be met in their graphing practice.

References


