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ABSTRACT

The interpretation of data and construction and interpretation of graphs are central practices in science which, according to recent reform documents, science and mathematics teachers are expected to foster in their classrooms. However, are (preservice) science teachers prepared to teach inquiry with the purpose of transforming and analyzing data, and interpreting graphical representations? That is, are preservice science teachers prepared to teach data analysis and graph interpretation practices which scientists use by default in their everyday work? The present study was designed to answer these and related questions. The responses of preservice elementary and secondary science teachers, practicing science teachers, and scientists to data and graph interpretation tasks were investigated. This study finds that despite considerable preparation, and for many, despite B.Sc. degrees, preservice and practicing teachers do not enact the ("authentic") practices that scientists routinely do when asked to interpret data or graphs. Detailed analyses of written or videotaped answers on the tasks are provided. This report concludes that traditional schooling emphasizes particular beliefs in the mathematical nature of the universe that make it difficult for many individuals to deal with data possessing the random variation found in measurements of natural phenomena. (Contains 10 figures, 7 tables, and 49 references.) (Author/CCM)

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"Do-able" Questions, Covariation and Graphical Representation: Do We Adequately Prepare Preservice Science Teachers to Teach Inquiry?

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Running Head: Covariation and Graphical Representation

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ABSTRACT

The interpretation of data and construction and interpretation of graphs are central practices in science which, according to recent reform documents, science and mathematics teachers are expected to foster in their classrooms. However, are (preservice) science teachers prepared to teach inquiry with the purpose of transforming and analyzing data, and interpreting graphical representations? That is, are preservice science teachers prepared to teach data analysis and graph interpretation practices which scientists use by default in their everyday work? The present study was designed to answer these and related questions. We investigated the responses of preservice elementary and secondary science teachers, practicing science teachers, and scientists to data and graph interpretation tasks. Our investigation shows that despite considerable preparation, and for many, despite B.Sc. degrees, preservice and practicing teachers do not enact the ("authentic") practices that scientists routinely do when asked to interpret data or graphs. Detailed analyses of written or videotaped answers on the tasks are provided. We conclude that traditional schooling emphasizes particular beliefs in the mathematical nature of the universe that make it difficult for many individuals to deal with data possessing the random variation found in measurements of natural phenomena.

> If scientists were looking at nature, at economies, at stars, at organs, they would not see anything. . . . Scientists start seeing something once they stop looking at nature and look exclusively at prints and flat inscriptions. . . all laboratory observers ha[ve] been struck by the extraordinary obsession of scientists with papers, prints, diagrams, archives, abstracts, and curves on paper. (Latour, 1990, p. 39)

Ethnographic research in scientific laboratories and scientific field work has shown that designing investigations, collecting data, transforming data, and interpreting the resulting representations are some of the quintessential scientific practices (Latour, 1993; Roth & Bowen, 1998). Recent reform documents have increasingly called for such "authentic" practices in mathematics and science education which would allow students to engage in these subjects in ways that correspond to everyday practices in these fields (AAAS, 1993; NCTM, 1989; NRC, 1994). For example, mathematics curricula in Grades 5-8 should enable students to (NCTM, 1989):

- describe and represent relationships with tables, graphs, and rules; (p. 98)
- analyze functional relationships to explain how a change in one quantity results in a change in another; (p. 98)
- systematically collect, organize, and describe data; (p. 105)
- estimate, make, and use measurements to describe and compare phenomena; (p. 116)
- construct, read, and interpret tables, charts, and graphs; (p. 105)
- make inferences and convincing arguments that are based on data analysis; (p. 105)
- evaluate arguments that are based on data analysis; (p. 105)
- represent situations and number patterns with tables, graphs, verbal rules, and equations and explore the interrelationships of these representations; (p. 102) and
- analyze tables and graphs to identify properties and relationships. (p. 102)

These competencies mirror the daily practices of scientists with their focus on data collection, analysis, and presentation and are thus easily integrated with science curriculum reform at the same grade levels. In fact, the integration of mathematics and science school activities may not only be interesting because children collect their own data, but may be essential for developing a thick layer of experiential knowledge that underlies much of scientists' understandings (Roth, 1996; Roth & Bowen, in press; Roth, Masciotra, & Bowen, 1998). Such integration of rich experiences with physical phenomena and subsequent transformation and analysis of the data appears to lead to robust mathematical *and* scientific understandings of phenomena (Greeno, 1988; Roth & McGinn, 1998).

To date, many science and mathematics teachers have not yet realized the potential that lies in situating mathematics in students' self-directed inquiries about natural environments as a way to implement these NCTM standards. Moreso, there is some evidence that science teachers may not enact competent data interpretation themselves (Roth, McGinn, & Bowen, 1998) making it difficult for them to scaffold students in these practices. The present study is therefore fundamentally concerned with the question, "Are (preservice) science teachers prepared to teach through open-ended inquiry?" Specifically, we were interested in answering questions such as "How do (preservice) science teachers analyze a given set of data previously collected and presented by Grade 8 students?," "How do (preservice) science teachers interpret a graph from published research?," and "How do preservice science teachers analyze and interpret data which they themselves collected and transformed?" Furthermore, we were interested in understanding the (preservice) teachers' performance relative to scientists analyzing the same data and interpreting the same graphs which were presented to them.

Inscriptions: A Social Practice Approach to Representations

Our theoretical approach for studying science in schools, university, and professional practice is informed by the emergence of anthropological, ethnomethodological, and sociological studies of scientists at work (Latour & Woolgar, 1986; Lynch, 1985; Traweek, 1988). All of these studies take a common perspective of science as a set of practices that are shared by members of specific communities—which is in contrast to more traditional work on science that saw in scientists a special breed of people who use special skills and procedures to cull facts from nature. Thus, these studies of scientists at work view knowledge not as something residing exclusively in the heads of community members but rather as something constituted, to a large extent, by the ways people (e.g., scientists) go about their daily business, how they justify what they do, the stories they tell, and so on.

Inscriptions are two dimensional representations of data that can then be transformed into other inscriptions; ultimately, they are included as tables or graphs in scientific publications. Inscriptions are therefore the result of scientists' work which converts research experiences into a form that is easily shown to others. Using inscriptions, natural scientists have converted information about trees, moving lizards, soil, and screaming rats into representations which they can then use to help form the rhetorical basis of their claims (Latour, 1993; Lynch, 1990; Roth & Bowen, 1998). Inscriptions are central to the practice of science because they can easily be cleaned, transformed, superposed and labeled such that they can be incorporated as an evidentiary base into scientists' conceptual arguments. As part of scientists' argument construction, physical phenomena are moved through series of inscriptions that may include, in increasing order of complexity, such re-representations as maps, lists, tables, totals, means, graphs, and equations. Through these transformative processes and the resulting inscriptions, scientists both construct and see phenomena; without inscriptions there would be few scientific phenomena. Thus, using data sets to produce inscriptions which can be used in publications is a core scientific practice (Latour, 1987)—one that it would be expected that graduates from a science program would automatically use as part of structuring their arguments in a scientific investigation. This expectation is not unreasonable given that this degree of competency has been documented with younger students conducting independent inquiry projects; one of our own previous studies documented the extraordinary competencies of Grade 8 students in constructing and transforming inscriptions when they conduct their own field-based research (Roth, 1996).

The use of graphs, and other types of representations, is something that students of all ages have difficulty using appropriately (Leinhardt et al, 1990; Schnotz, 1993). In related studies we have detailed the difficulties which second year university science students had while interpreting graphical representations in seminar discussions (e.g., Bowen, Roth, & McGinn, in press). The foundations of the students' interpretive difficulties in seminar sessions were shown in a microanalysis of the text and gestures accompanying the presentation of graphs in the lectures for that course. This analysis suggested that the interpretive framework of the lecturer differed from that of the students and that this derived from different experiences at collecting and summarizing data and that the gestures over the graph were from one who "knew" the graph being unlike those which would be made by those who did not "know" the graph (Bowen & Roth, 1998a). Together, these differences lay at the root of the student difficulties observed in their seminar.

COVARIATION

Scatterplots, bestfit functions, and other graphs in Cartesian coordinates are ideal for representing the continuous covariation of two variables which would be difficult to express in words. Because of its typological character, language is well suited to expressing differences and categorical distinctions. On the other hand, graphs have a topological character well suited to expressing quantity, gradation, continuous change, continuous covariation, varying proportionality, and other complex topological relations of relative nearness and connectedness (Lemke, 1998). Graphs are sign forms which can therefore be used within particular communities to represent the topological and dynamic character of relationships. An analysis of scientific research articles from 5 journals covering over 2,500 pages showed that graphs which display the relationship of two or three variables are *the* preferred method of representation in science (Roth, McGinn, & Bowen, 1997). Sociological analyses have shown that graphs are predominant because, in the practices of scientists, they have the greatest rhetorical power (Latour, 1987). Although tables could also be used to show how the concurrent associations of measures of one quantity vary to that of another, the relationship across the entire data set is only implicit in tables whereas graphs make the association immediately available in visual form

(Bastide, 1990) allowing readers to note patterns in the data as well as discrepancies (e.g., outliers).

RESEARCH DESIGN

Tasks

This study was designed to understand (preservice) teachers' graph interpretation practices relative to the representations and transformations which they are expected to teach according to the reform document guidelines. We investigated these practices in three conditions. First, participants were asked to interpret a set of raw data presented on a map of the research site (Lost Field Notebook); the data did not easily reveal a relationship given the scatter and one potential outlier. Second, we asked participants to interpret a graph originally published in the scientific literature and which later, with modifications, appeared in textbooks and in an ecology lecture (Plant Distributions). Third, we presented participants with a task where they had to design their own investigations, collect data, transform data, and interpret the transformed data (Investigations).

These three tasks represent three different levels of "authenticity" as they would be experienced by students in post-secondary science programs. The Lost Field Notebook problem represents a "school-like" task such as students encounter in problems sets from university science seminars and lectures (Bowen & Roth, unpublished data). The Plant Distributions task asks students to provide an interpretation of a graph which is similar to those they would encounter when reading a journal article; a common task for senior-level science students conducted to support research activities on which students were reporting. Finally, the Investigations task reflects scientific practice in that it contains the components of most scientific research: framing a question, operationalizing variables, analyzing data, and making claims from that data. Together, these three tasks represent the main components of undergraduate science education which would deal with developing competency in conducting scientific research.

The three tasks also differ in terms of the translation processes required for making claims about the relationships between the relevant quantities (Janvier, 1987; Roth, Tobin, & Shaw, 1997). The Lost Field Notebook requires double transformation: first, the relationship between the measure has to be uncovered (e.g., using a graph, curve fitting procedure, statistical analysis, etc.) before the relationship can be translated into a verbal description of the situation that may have led to the particular data at hand. The Plant Distributions requires one translation, for the relationship is visually available. Finally, the Investigations task requires a complete cycle of activities from situation descriptions that identifies the variable categories, through measurement, representations, before another verbal description of the covariation can be related back to the situation. These translations are expressed in Figure 1. Unlike Janvier (1987), however, we pursue the translations not as psychological processes, but as social practices that are embedded in other social practices, and that are appropriated by individuals as they increasingly participate in communities where these practices are what everybody else is doing (Roth, 1996; Roth & McGinn, 1998).

[Insert Figure 1 about here]

Lost Field Notebook

The Lost Field Notebook task originated in an earlier study (Roth & Bowen, 1995) where it was designed to test a research hypothesis about practices of data interpretation among Grade 8 students engaged in a 10-week field study of different ecozones. The representation of the data in the map is a facsimile from the notebook of one Grade 8 student involved in the study. We wrote a stem that situated the data in the same context in which the children worked at the time in order to assess their data transformation practices using a problem that was as ecologically valid as possible. For the purposes of the current study, we selected one of the forms containing 8 plots and therefore 8 pairs of numbers (Figure 2.a). The graphical representation of the data in a Cartesian graph shows the ambiguity of the relationship (Figure 2.b). We chose this particular problem for at least three reasons. First, its apparent correspondence to a plausible experience seemed strong (even our scientists never questioned the authenticity of the data). Second, the problem is equivocal even for individuals with much more experience in research (e.g., graduate students). As Figure 2.b shows, the correlation changes from a nonsignificant to a significant relationship when Point C is considered an outlier and dropped from the analysis. This change in significance promised cognitive conflict (and discussions between pairs of participants discussing the task) and, for us, an opportunity to study sense-making over and about those representations that participants constructed to support their arguments. Third, the problem was interesting because it is quite similar (in the scatter of the data) to scientific data sets as they emerge from ecological field work (Roth & Bowen, 1998) and in ecology research journals (Roth, McGinn, & Bowen, 1997).

[Insert Figure 2 about here]

Plant Distributions

The Lost Field Notebook problem required some form of transformation before any conclusions about the natural environment could be made. Problems in the interpretation potentially arise even when the covariation is already represented in graphical form. We therefore chose a second task with a similar underlying variation (i.e., plant density as a function of a physical variable). To ascertain closeness to scientific practice, we chose a graph from the ecological literature (Eickmeier, 1978), but modified it in ways similar to those used as lecture material in a university lecture course (i.e., clarified captions, reduction of variation in major trend-line patterns; Bowen & Roth, 1998a). The original research by Eickmeier was conducted to show that, consistent with a theoretical model about adaptation and niche exploitation, different photosynthetic mechanisms allowed plants to best thrive in different climatic conditions. C3 (Figure 3) is the simplest, but most water consuming mechanism based on a one-cycle chemical process. The C4 mechanism conserves water by adding another cycle of chemical processes. The

CAM mechanism is similar to C4, but the second cycle occurs in separate cells, so that gas exchange associated with the first process can occur at night; this process is separated from the second one which occurs during the day thereby minimizing water loss through the pores.

Insert Figure 3 about here

Modification of the inscription occurred in two ways. First, several local minima in the functions were eliminated to make for more continuous curves. Second, the temperature and moisture gradients were plotted above the graphical display. We used a caption similar to those found in the scientific literature, and added a reference to the literature so that respondents could see that the graph had come from the scientific literature. In this way, the graph was not unlike those several hundred identified and analyzed during a previous study of five ecology journals (Roth, McGinn, & Bowen, 1997). Participants were asked by us to describe how they interpreted the graph and to provide us with their understandings of what it might represent.

"Authentic" Investigations

Responding to tasks provided in the form of the previous two problems, though considerable context had been provided, can be criticized as too school-like in that the data and representations are preframed (Lave, 1992; Roth, 1996). We therefore asked one subset of our participants to design and conduct an investigation in which correlations between biotic and abiotic features of the environment were to be studied. They were told that the investigation should be framed in the form of two focus questions and include relationships based on some form of quantitatively measured variables. The students were to report their results using a scaffolding device, the Epistemological Vee (Novak & Gowin, 1984), to which they had been introduced previously. This device explicitly prompts users to state research questions, provide a brief description of their research method, report data, transform the data, and state claims based on the data. Because users are required to state their prior knowledge also, they can, after the fact, assess their learning in the process of the inquiry. We asked two of our scientist participants to comment on selected case analyses of reports written on these investigations.

Research Participants

Preservice Elementary Science Teachers

These participants were enrolled in a Western Canadian university in their last year of a five-year elementary education program and had chosen science and mathematics as their subject matter specialty. They had taken a number of related courses, beyond the minimum required, in order to receive their specialist degree. The 10 preservice teachers (7 female, 3 male) constituted the entire class of an advanced science curriculum course, the only one offered during that school year. Nine of these preservice teachers had above-average GPAs in the elementary education program. (All pseudonyms start with the letter E to indicate students in the elementary education program.)

Preservice Secondary Science Teachers

These participants were enrolled in a secondary science teacher preparation program in a different university in Western Canada which accepts applicants only after they have previously completed a bachelors degree. All 25 students (10 male, 15 female) had previously completed undergraduate degrees with a major either in science (22 students), mathematics (2 students), or in the arts (1 student). Four students had obtained post-graduate degrees in: veterinary medicine, mechanical engineering, chemistry, and law; they also had work experience in their respective domains. (All pseudonyms start with the letter T for teacher.)

Practicing Science Instructors

Four science teachers (2 high school teachers, 2 university instructors) all with a B.Sc. degrees (ecology, 2 biochemistry, physics) participated in the study. Three had participated in research as assistants, but none had conducted independent research for the purposes of publishing the results of their studies. Their experience ranged from first year to more than 20 years of teaching. (All pseudonyms start with the letter I for instructor.)

Practicing Scientists

Over the past two years, we have asked 25 practicing scientists to interpret various scientific representations, including different sets of data and graphs. All sessions were videotaped and transcribed. For the present purposes, we included 15 individuals, 10 individuals who responded to the Lost Field Notebook problem and 10 individuals who responded to the Plant Distribution Graph (with 5 individuals doing both). The individuals had a minimum of five years of research experience and at least a M.Sc. degree. The domains of their work differed widely including ecology, entomology, marine biology, physics, chemistry, and forest engineering. (All pseudonyms start with the letter S for scientist.)

Task Distribution

The participants contributed to different extents, formats, and social settings in our data base. The distribution of think aloud, group sessions, and written task environments across the different participant groups is shown in Table 1.

[Insert Table 1 about here]

Data Sources and Interpretations

The present study was developed from a data corpus that includes (a) videotapes of individuals (scientists, science teachers) and groups (preservice elementary science teachers) solving the Lost Field Notebook problem and interpreting the Plant Distribution Graph; and (b) written solutions by individuals (Lost Field Notebook) and groups (Authentic Investigation) from the preservice secondary teacher population.

Our interpretations inscribe themselves within the larger context of studies on the interpretation of scientific representations from middle school to professional practice; our studies draw on semiotics of scientific texts (Bastide, 1990; Eco, 1984) and interaction analysis (Jordan & Henderson, 1995) as the major methodological frames. We analyzed the data individually (in part to later assess the robustness of our categorizations) and, later, in collaborative sessions. In daily meetings, we generated assertions and tested them individually and collectively in the remainder of the data base. The transcripts and videotapes were taken as occasions for construing the public work done of providing a solution; in the cases where we had videotapes of pairs, it was expected that, if there was any trouble during the interpretation, the participants would try to remedy the breakdown by talking to each other. Our transcripts were therefore protocols of individuals' and groups' efforts in making solutions to the tasks as they understood them accountable to the researchers or to each other.

FINDINGS I: INTERPRETING RAW DATA

Our overarching question was whether (preservice) teachers enacted the scientific and mathematical practices described by reform documents (NCTM, 1989) in appropriate situations. Specifically, our first question asked "How do (preservice) science teachers analyze a given set of data previously collected and presented by Grade 8 students?" To contextualize the answers by (preservice) teachers, we present scientists' responses to the same task.

Scientists' Readings

If you possibly plotted out the graph, then did a linear regression on it, you might see an R^2 value that actually makes sense.

In the course of our inquiry, we asked ten active researchers working either at a university or in the public sector, and all of whom had M.Sc. or Ph.D. degrees, to examine and provide an interpretation for the Lost Field Notebook problem. Without exception, these participants ended up plotting the data, proposed regression analysis to test goodness of fit, discussed an outlying data point, and suggested the collection of additional data to increase the power of the statistical analysis. The scientists were unanimous that, to make a convincing claim, they had to plot the data and provide statistical indicators about the strength of the relationship. Providing a data plot and the statistical information would be their way of supporting the claims. Without exception, all practicing scientists indicated that there appeared to be a relationship which should be substantiated by statistics and collection of further corroborating data.

Scanning the Map

Three scientists, after reading the story plot, immediately, without scanning the data and without hesitation, suggested plotting the data and subsequent statistical analysis. The others engaged in a more lengthy process of scanning the map, making tentative claims, plotting the data, and then conducting their analysis followed by statement of claims. The difficulty in our analysis lay in assessing what occurred during the first few seconds of seeing the map, because few participants verbalized what they focused on. But a few did. In the first reading, things become salient, that is, the reading establishes a domain ontology. Some scientists noticed the irregular plots, but this aspect did not enter their interpretion at all.

Scanning for extreme cases and data points at "opposite ends" of the data range was a common practice. Thus, some scientists began by seeking those areas with the lowest light intensity or bramble density, and then moved to identify those with the highest values on the same variables.

> I'm looking at, say just these three which were the lower ones in this corner [top right], 750 to 500, and then looking at these three [D] [H] [E], 12, 15 are of the two highest levels and these [C] [F] are the two lowest levels. [Stu]

As they scanned the map, scientists noted the potentially discrepant data. But rather than using these data for drawing conclusions, this noting was simply part of establishing the domain ontology, which also included other aspects such as the irregular size and boundary of plots, the absence of "edge effects," the differences in the size of the plots, or the identification of those plots in which the extreme cases on either variable were located.

Tentative Claim

The first, tentative claims after scanning the map were not consistent. In equal numbers, the scientists initially suggested that there was and was not a pattern, that is, a relationship between the two variables light intensity and bramble density. A typical statements was:

> So, at first glance, it would seem that there is not much of a pattern or a relationship between foot-candles and percent coverage by brambles. [Steve]

At this point, rather than using individual data points for or against their claims, scientists then proposed to plot the data. Some immediately proposed subsequent statistical analysis to find correlations, and then outlier analysis.

> If you possibly plotted it out, plotted out the graph, then did a linear regression on it, you might see an R^2 value that actually makes sense, that's why I would plot this data if I was, wanted to see a pattern. So just looking at it like this, doing a linear regression plotting percent cover versus light intensity, see if there is a line there, then calculate R^2 and if we did that we probably would see some kind of a pattern with increasing cover and increasing density, so, more light equals higher density of brambles. [Stu]

Data Plot and Analysis

Scientists plotted the data, and with one exception, used light intensity on the abscissa and bramble density on the ordinate. After the data were plotted (as in Figure 2.b), scientists were unanimous about the (weak) relationship between the two variables. They then engaged in an analysis of discrepant data. For example, after having suggested that there "vaguely was one" relationship, Sally assessed the effects of possible outliers.

> Take that out [C], take that [D] out. Just to remove outliers, so if you remove an outlier to see if there is, if it's a single point that sort of driving the whole relationship. So if you take that [C] one out, it's not bad. But like this one [D] up here, if you take that out, I'd say . . . you're grasping at a relationship. And if you take that [H] one out, it doesn't

> change it too much. I would go to this point [F] is that 500, 0, no, this one [C] is 500 foot candles, 30%, see that one [C] looks a bit suspicious because there is so much variation between those two. [Sally]

After this analysis, Sally concluded that there was a "positive relationship between foot-candles, or the amount of light they get and how many brambles there are."

There was only one scientist who proposed a curvilinear relationship. In contrast with the other scientists, he plotted light intensity over bramble density which provided him with a different perspective. He drew a best fit curve which was parabolic and then explained (Figure 4):

> The only pattern I might see is that pattern GESTURES[parabola], somewhat like that, but not a super strong one. That suggests that there is some intermediate light level at which bramble coverage is greater. So I might claim that brambles have a optimum light level intensity in which they grow and reproduce optimally at, and the higher or lower light levels, their growth and reproduction is decreased. [Steve]

[Insert Figure 4]

In dealing with the outliers, scientists suggested the collection of additional data, checking whether there were copying errors from a notebook, or seeing if there's "something weird about that region that results in either high ones, that resulted in a really high percentage with such a low." One scientist proposed running consecutive regression analyses:

> There are statistical tests that can be used, curve fitting. The simplest one is straight line relationship, the R^2 statistics tells you how well the best fit straight line through a series of data points fits and now you can run that leaving certain data points out or leaving all the points out sequentially and seeing which one gives you the best R^2 or the best fit. [Stu]

Another scientist proposed the use of statistical indicators such as Mahalanobis and Cook's distances which can assist in deciding whether an outlier significantly affects the relationship, and whether or not a data point could be dropped. (Many statistical packages have this option.)

Other Factors

Our prior research suggested that many non-scientists seek to explain the variation in both variables by drawing on explanatory resources outside of the written problem itself. That is, drawing on personal experience, they invoked other variables that might explain the particular data set in front of them. This was corroborated in the present study among the non-scientist individuals. On the other hand, scientists were only marginally concerned with other possible factors. Usually these concerns became evident before they actually plotted the data. For example, one scientist, after the first scan of the map, suggested that two plots [C,F] had particularly low light intensities which he thought were possibly due to shading by other trees. Another individual suggested that a water source at the western edge might be a mediating factor.

Suggestions for Improving Elizabeth's Study

Scientists were almost unanimous about the fact that the number of data points should be increased, though at least one suggested that she herself had conducted and reported research based on 12 data points. Another common suggestion was to try and work with plots of equal size, though the scientists also realized that density was a relative measure and light intensity had been averaged across the plots. One scientist also suggested that it might be better to work with the absolute numbers of brambles in areas of normed size, but was uncertain whether this would improve the quality of the measure.

> You could actually calculate the absolute amount of brambles, which might be a better measure. I mean, ideally it might be better trying to layout defined, like areas of equal size. [Sally]

Think Aloud Protocols by Instructors

There has to be another variable involved in what's happening here because a direct correlation between light intensity and percent density of the bramble doesn't seem to hold true.

Four instructors (2 university, 2 high school) with B.Sc. degrees were asked to think aloud as they completed the Lost Field Notebook problem. All four, without exception, inspected the data and, without any transformation, claimed that there was no relationship between light intensity and bramble density.

> I mean it seems, you know, the higher [D], the higher light higher coverage, but then when you look at like between 200 [D] and [E], between 1200 [D] and 1500 [E] it looks like that but then when you look at this one [H], well, that's not very high, so why not? like [D] [E] it doesn't [H]. [Ina]

Tentative Hypothesis and Testing

Three of the four instructors engaged in cycles of explicitly verbalizing at least one tentative hypothesis, and then rejecting this hypothesis based on an analysis of individual data points. "High percent, lots of light [D], low percent, lower light [G] higher light and higher percent [B]" (Ike) "it seems, you know, the higher [D], the higher light higher coverage" (Ina).

> One could argue that all brambles need light but then that's defeated by the fact that we've got light 500 foot candles here [F] and no brambles at all. One could argue that brambles need more than 500 foot candles to grow but that's [C] defeated by the fact that you've got 30% incidence with the self same 500 foot candles that over here [F] was not growing anything. [Ira]

[Insert Table 2 about here]

Three of the four used pairwise comparisons of data points (Table 2). In a few instances, three [D,C,E] and five areas [A,B,F,G,H] were clustered to obtain geographical patterns. In these instances of comparisons, two types of comparisons were used, within variable comparisons and between variable comparisons starting either with the light intensity or the density comparison. Usually, this pattern was used to show exceptionality, that is, for an equal or similar value in one variable there was a drastic difference in the measures of the other variables such as in the comparison of [C] and [F], 500:500:::30:0.

One person (Ira) used the trend within a pairwise comparison as a counter argument against an overall trend. Thus, whereas the light intensity increases going from Plot D to Plot E (1200:1500), the opposite trend is observable for the coverage (40:30). This was interpreted as indicating a negative relationship held against an overall positive correlation.

Two individuals [Ira, Ian] crossed the arguments. For example, then comparing the areas [C] and [D], the argument ran 40:1200:::1250:15 ("40 is what you were seeing at here [D], 1200, while this [H: 1000] is down to 15% here [H: 15]").

Two individuals [Ian, Ina] considered three data points as they searched for consistency among data points. Ian compared the data set [H,A,D] in both a between [1250:15:::1000:10:::1200:40] and within [1250:1000:1200:::15:10:40] condition concluding in both cases that [D] was a discrepant point with respect to coverage. His other three-point comparison consisted of the set [DCE] for which he used a within comparison [40:30:30:::1200:500:1500] to conclude that [C] showed a discrepancy with respect to light intensity. Ina tested the hypothesis "higher light, higher coverage" and then proposed the set [DEH] to reject it [1200:1500:1250:::40:30:15] because the coverage in [H] was low.

Although each individual made a number of comparisons, when they were asked what they claimed and how they supported it, they generally used one example to contradict the relationship between light intensity and bramble density.

Pattern Map: "There is Something through this Area"

As they abandoned the search for relationship between the two variables, individuals proposed geographical pattern in which the western edge [D,C] and Plot [E] with high bramble densities were opposed to the low densities in the remaining areas.

> I have a hard time saying the more light, the more brambles 'cause that's not entirely true. It's almost as if there is something down through this segment CIRCLES [G,B,F,H,A] of the land here that's just decreasing the amount of brambles, and this [E], and this [D], or this [E] is an erratic, I'd be curious if something happened on this side POINTS[right map boundary] [Ian]

One person suggested that Plot E may be an outlier to the general pattern of the east-west (right-left) geographical pattern of bramble density. Thus, whereas we initially assumed pattern maps to be an independent strategy (e.g., Roth, 1996), the present data suggest that participants only engaged in this practice after exhausting other options and after suggesting that a covariation does not exist.

Other Factors

All four proposed that any weak relationship was spurious and that factors other than light determined the density of brambles.

> But the thing that she is actually measuring is the differences in soil quality, for example, or differences in water in the different areas. [Ina]

Whereas the physics instructor (Ian) did not get into any specific alternative, the others proposed a variety of factors including water, soil quality, soil characteristics (such as a rocky outcrop underneath Plot F), and seed distribution. One person (Ina) also suggested that more data should be collected in order to make more founded claims and check whether the distribution of the plants within each plot is fairly homogenous or whether the plants come in clusters. Another individual (Ira) thought that, because of the small size of the area covered by the map, there might possibly be considerable experimental error in the determination of the bramble density.

Preservice Teachers' Readings: Prior Work

A pilot study ($N = 17$) and an initial survey ($N = 32$) (Roth, McGinn, & Bowen, 1998) based on written tests showed that only a small fraction of secondary preservice teachers (5 of 49), despite their prior B.Sc. and M.Sc. degrees (most of them in biology), used graphical and/or statistical analyses when responding to the Lost Field Notebook problem. Statistical comparisons revealed that there was a significantly higher proportion of Grade 8 students (who solved the problem in pairs) who used graphical and statistical analysis methods than secondary preservice teachers. Having classified responses into more abstract representations (graph, averages), less abstract representations (ordered table, pattern map, list), and no transformation (language-based), we detected a significant effect ($\chi^2(2) = 6.80, p < .05$). There was a lower incidence of more abstract representations among preservice teachers than among pairs of Grade 8 students. Furthermore, there was a relationship between the type of analysis and the type of claim respondents made. A logit analysis—with type of claim (correlation, no correlation) as dependent variable and type of representation (more abstract, less abstract, none) as independent variable—showed that an equi-distribution model had to be rejected, $\chi^2(3) = 16.42, p < .001$. Analyses by respondents based on statistical and graphical methods generally suggested a positive correlation between light intensity and bramble coverage, whereas analyses based on other methods generally ended in claims that there existed no relationship between the two variables.

In the present study, we had two objectives. First, we wanted to collect verbal protocols of individuals and pairs to better understand the processes by means of which (preservice) teachers arrive at the particular claims and how they select the method for supporting their arguments. Second, we assumed that preservice teachers in the previous study, despite their scientific training (and B.Sc. degrees), did not use graphical (or statistical) analysis because they had not recently engaged in activities in which drawing graphs and doing statistics is "what is normally done" and "What everyone else does." We expected that the frequency of graph use would increase if the participants were primed. We therefore repeated our earlier studies with preservice secondary science teachers but in a new condition: We primed participants immediately prior to the Lost Field Notebook with an activity that required them to answer the question, "How does the height from which you drop a ball affect the bounce?" by collecting and recording data, transforming the data into a Cartesian graph, and drawing conclusions from this graph. Specifically, they were asked to construct a scatter plot and to base their interpretation on this plot. Participants recorded the entire activity using the "epistemological vee" (Novak & Gowin, 1984) as a scaffold which provided prompts for them to engage in particular steps, from question to design, data collection, data transformation, analysis, and statement of claims. However, we also expected (based on our 20 years of combined experience teaching science in middle and high schools) that, because they had little prior experience in data analysis, at least some participants would reject a relationship between the variables in the LFN problem because the data did not fall on a (straight or curvi-linear) best fit graph.

Individual Written Answers after Priming (Preservice Secondary Teachers)

The missing field notebook exercise was very difficult for me.

As in the previous study, and despite their science degrees and the priming, preservice secondary science teachers found the Lost Field Notebook activity difficult. One of the individuals who produced a data plot with a line of best fit suggested:

> It is very clear to me that I was taught science as a collection of facts, not as an exploration. This exercise was very difficult for me. I can see its usefulness already. I think it is important to have this kind of "thinker" exercises included in the curriculum. [Todd]

Another person suggested, "What was that Lost Field Notebook exercise all about? I couldn't make any sense of it. Now I really feel like a non-science type" [Tandy].

Drawing on Latour (1987) and our own prior work, in this study we categorized answers along a continuum {no transformation (verbal)—>Ordered Table—> Ratios, Data Plots, Data Plots + Bestfit}. Table 3 shows that, possibly as a result of the priming activity, a large fraction of participants drew graphs (44%) compared to our previous studies. However, there were only 7 individuals (26%) who used lines of best-fit (two with outlier analysis) in the way we observed the scientists use them. Furthermore, we found an almost clean break between the claims made by those participants who plotted data accompanied by best-fit and outlier analysis and all other solutions, including those that had only plotted the data: Those who claimed that there was a relationship in the complete set of the data had all used in their analysis a line of best-fit. Generally, there was a much larger number of enumerations and discussion of other possible factors that determined bramble density among those responses that did not use plots and lines of best-fit and therefore claimed that there was no relationship between the two variables. There were only 7 cases where quantitative comparisons between two data points were made, 6 of which were related to a comparison of Plots C and F.

[Insert Table 3 about here]

Data Plots, Bestfit Lines, and Outliers

Figure 5 shows one of the solutions in which data are plotted, a line of best fit drawn, and the analysis of one data point as an outlier. Four of the pre-service secondary teachers also constructed a table which appeared prior to the graph on the answer sheet; two individuals initially suggested on the basis of the table that there was no relationship, one person (Ph.D. in mechanical engineering) disregarded the table in favor of the graph, and the fourth person had constructed a table in which the light intensities for same-value coverages were already averaged permitting the conclusion of a positive correlation.

[Insert Figure 5 about here]

One individual, before plotting the data, prepared a data table ordered according to the percent coverage but for each value, averaged the associated light measurements. She then plotted the reduced number of data points (5), produced a line of best fit and concluded that there was a positive relationship between the "% brambles and # fc."

The one person who concluded that there was no relationship despite having drawn a line of best-fit, initially began with an ordered table. She argued that the "variance from the line of best fit suggests an inconclusive relationship. . . supported by the fact that both 0% and 30% have a value of 500 foot candles" (Tora). In this, her argument was similar to those by the individuals using data plots only without accompanying lines of best-fit and outlier analysis.

Data Plots Only

When participants used data plots but without accompanying lines of best fit, the claim in all cases was that a relationship did not exist (Table 3). Of the five claims, three were supported by citing discrepant data points, the remaining two simply by referring to the scatter of the data that did not permit the attribution of a clear relationship.

> It would appear that an increase in foot-candles in and of itself does not consistently result in an increase in brambles. Rather, it would appear that the amount of outside (presumably unobstructed access to light) area is indicative of the increased brambles. For example, if you compare the outside unobstructed light of the one with the smallest amount [F], the density is 0% versus the one that is in the triangular area [C] which has a larger unobstructed area having a density of 30%. [Tabby]

One student [Tanya] split the entire field in an upper and a lower area and produced plots for each set of four data points separately. For the plot containing the data of the upper four areas {D, G, B, F}, she claimed the existence of a relationship whereas in the case of the remaining data, she claimed that there was no relationship. An analysis of the two graphs shows that in the first instance (Figure 6.a), the data can be thought of lying on a curve, whereas this is not the case for the second plot (Figure 6.b). This analysis further supports our claims that participants who have not engaged in science as daily routine activity tend to assume that relationships between variables have to be ideal in the sense that data points fall on (curved or straight) lines. If this is not the case, as the differentiation between Figure 6.a and 6.b shows, a relationship is not defended, or participants argue that the relationships are mediated by some other variable. All of this suggests a deep-seated assumption and mundane sense—which has existed since the early Greek philosophers—that nature and mathematics are isomorphic, that is, that the world is fundamentally mathematical. Thus, if there is not a 'clean' relationship between two variables—if all data points do not fall onto a line—it is assumed some other variable is mediating the relationship or that a relationship just does not exist.

[Insert Figure 6 about here]

Ordered Table

Five participants constructed tables of ordered values; all individuals ordered their tables on the basis of the approximate coverage; one individual also constructed a second table in which the data pairs were ordered according to the second variable.

There is not an overriding correlation between the light and density of brambles. Areas with 1250 fc and 1200 fc respectively, have 15% and 40% density, respectively.
Question: Could soil content or pollution, slope, drainage, have an equally strong effect

on plant distribution? The proximity of the areas of low density would indicate a spill (killer) or type of adjacent soil that does not enhance growth. [Tammy]

Four of the five individuals suggested that either the investigation needed to be re-done or that additional measurements on other variables possibly mediating the relationship were necessary (including nutrients present, soil type, moisture, moisture retention, animal predation, pollution, slope, and drainage).

No Data Transformations (Verbal)

Without a transformation of the data into some other mathematical form, it is difficult to make claims about the relationship between two variables under consideration, and therefore contribute to the construction of a phenomenon (which here would be light fosters plant growth). In contrast to our earlier research which had shown that both preservice secondary science teachers and Grade 8 students split their claims with respect to the existence of a relationship (yes/no), in this study all respondents who did not transform the data claimed that a relationship did not exist between light intensity and bramble density. The following answer was provided by Tilson (honors B.Sc. in biology, environmental science)

- It is difficult to draw conclusions on patterns from these field notes because she has broken the data up into small sections—so it is difficult to make conclusions.
- I don't perceive any patterns between % of bramble cover and the amount of light.
- The use of % bramble cover is misleading because it is referring to different area sizes.
- The highest bramble coverage seems to be along the left and bottom sides of the study area—perhaps this is an edge of some kind, or perhaps there is a path of bramble running along this edge. The light is strongest along this edge as well, except for along the weird slanted side—perhaps this is a building or wall which is blocking the light.

In addition to the problems of perceiving patterns from the raw data on the map, this participant also argued, in contrast to general practice, that the relative coverage is a function of the plot size. However, it is not clear whether in this case the argument drove the claim or if the argument emerged after a pattern was not detected. As many other individuals who claimed that there was no direct relation between the two variables, Tilson then sought patterns in the geographical distributions and then hypothesized about possible natural features (i.e., other factors) that might cause such a distribution.

Other solutions

Two solutions did not fit into our previous scheme and were, because of their limited frequency, categorized as "other." One individual re-drew the map to scale including three cross-sectional lines and beneath it, plotted the average bramble coverage against location. In this way, she engaged in the construction of "transects," a common practice in ecological field work related to plant distributions (see next section).

Collaborative Readings by Preservice Elementary Teachers

We don't know enough information to make many patterns.

Among the preservice elementary teacher pairs we found similar claims and quantitative arguments as among the preservice teachers (secondary) with bachelor degrees. However, as is seen in Table 4, the number of quantitative comparisons was lower (in relative and absolute terms), and between (rather than within) strategies were predominantly used. As before, the comparisons between CF, DE, and DH made for the bulk of the numerical comparisons. One individual proposed the existence of two subareas, in each of which there was a different kind of relationship.

> Yeah, GESTURES[D<—>B] like if it was to say that these are all correlated there's some kind of connection with these at the top or there is something at the bottom, it just don't go either, I mean, 'cause 10% should be 750 whereas 40% is 1200. [Erna]

[Insert Table 4 about here]

In contrast to the instructors with B.Sc. degrees, the preservice elementary teachers made many comparisons in which one or both measures were compared on qualitative grounds.

> Because here's 1250 [H] and 1200 [D], which are very similar, and there's [H], that's [D] like more than twice as much. This [C] is 0 [F] and 30 [C] right, so we can't really see a pattern between the light and the percent of brambles. [Etta]

> You're going up here [H,G] in this stretch And you go from pretty much the same amount of coverage, pretty close, but there's a huge amount of light difference. [Ella]

In these cases, the comparisons are not based on ratios. Erin first compared the coverages of C and D, and achieves as result "10% less." She then compared this to the "half the amount of light." In Etta's case, the H and D areas are "very similarî in terms of light intensity, which is compared to the "more than twice as much" in coverage. The argument of similar then carries over into the comparison of C and F (each 500 foot candles), but with drastically different coverage. Ella's argument also rested on a comparison of similarity in one measure (they are both 30%), whereas on the other measure, "[E] got way more light than [C]."

"Maybe It's a Pathway or Parking Lot or Something"

In four of the five groups, numerical and qualitative comparison of the measures predominantly occurred during the first half of each session. Thereafter, the task definition appeared to change from seeking a relationship between the variables to one in which students attempted to explain why Elizabeth might have obtained the particular measures she had. When it gets complex problem solvers, whether copier repair people or economists, appear to use narratives (Bruner, 1986; Orr, 1990). Explaining the geographical distribution of the light and or bramble coverage:

I think there must be a pattern in here maybe with the source of light, because if we've got, for some reason, it seems to be going this way [E—>D] and then when it breaks of that [west] way then [east] it's less, you know what I mean, because we got 15 [E], a 1000 [A], a 1250 [H] and a 1200 [D] and then when you go. [Erin]

The groups generally focused on the geographical distribution of light intensity and bramble density. In four groups, participants elaborated on possible effects due to the movement of the sun, blockage of light by objects (hill, rocks, fence) or plants (trees, brambles in neighboring plot). One major concern in these groups was the lack of brambles in Plot F leading to varying reasons being proposed: sidewalk, compost heap, cement patio, rock outcrop, parking lot, yard, pond, and rocky cliff or slope were proposed as possible features that did not permit brambles to grow in this plot. Among the factors considered more generally which might mediate the growth were differences in soil quality and type, depth of soil, ground water, water received through rains or sprinkler systems, and competition by other plants (weeds or trees) crowding out the brambles.

"How did they measure the foot candles of light?": Questions of Method

Three respondents wondered about the areas and suggested that their shape was possibly determined by the percent coverage. For example, some wondered whether the shape of Plot D was determined by that area in which the average coverage was consistently 40% (Erin, Eli) or because the plots are "separated by the among of light they receive" (Eva). Erna suggested that in her experience, sampling areas were either round or square, but never irregularly shaped. Others suggested possible features such as pathways (Erna, Ed) that might have determined the particular shape of the plots. In two groups, participants asked for reassurance that the maps were correct and whether these maps actually corresponded to the research area. There was also a question whether the light measurement was read appropriately from the instrument.

Discussion of LFN Solutions

This part of the study showed that whereas scientists all defaulted into the same practice (transformation of data into Cartesian plot, statistical analysis, outliers), the (preservice) teachers enacted these practices only when primed with a similar activity. Even then, only a minority (26%) engaged in best-fit or trend analysis. That is, at this point, most (preservice) teachers do not enact the default interpretive practices which we observed among the scientists. One evident difficulty affecting the teachers' interpretations was that the data did not fall on a neat line but were scattered. Variation of one variable for the same or similar values of the other were used as evidence to argue that covariation did not exist in the data set.

The most discussion of individual data points (quantitative and qualitative taken together) occurred among the pairs of preservice elementary teachers (5.2 per group); fewer among the instructors (4.0 per individual); and least among the written answers from the preservice secondary science teachers (0.4 per individual). An analysis of how the comparisons of the data points were deployed in the argument shows that the predominant number of these (31 numerical, 9 qualitative) were used to argue that with same or similar measures on one variable, there was considerable variation on the other (Table 5). Fewer comparisons were used to either argue that there was a pattern of the type low light:low coverage:::high light:high coverage (7) or that there was an inverse relation indicated: When two data points are compared, an increase in one variable associated with a decrease in another variable was made three times.

[Insert Table 5 about here]

Arguments against a relationship between light intensity and bramble density based on the comparison of individual data pairs shares similarities with the model-based reasoning employed by college students on algebra story problems (Hall, Kibler, Wenger, & Truxaw, 1989). Our participants in this category reasoned directly within the situation glossed by the problem rather than relying on mathematical formalisms. They proposed a relationship and then used specific instances in which the hypothesized pattern was violated, or used a specific instance as counter argument for a relationship. Table 5 indicates that, if qualitative and quantitative comparisons are considered together, there was a considerably larger number of within variable comparisons than between or cross variable comparisons ($\chi^2(2) = 22.8, p < .0001$).

Our participants' search for the firm association between variables is not something that should be attributed to some cognitive deficit, for there are long-standing traditions among scientists themselves whereby firm, ideal associations are thought to underlie worldly phenomena. Early astronomers, and particularly Ptolemy, added an increasing number of circles (epicycles) in order to maintain a model of the universe based on circles. Just as our participants introduced additional factors to try and clarify relationships, Ptolemaian astronomers added additional epicycles to bring their models closer to the data points. Furthermore, recent evaluations of the research on the effect of cholesterol was mired in long, never closed controversies because scientists believed that close associations should exist, but no research ever could establish a clear relationship:

> The scientists conducting these studies were looking for the sort of diagnostic signal which was characteristic of pre-World War II medical success stories—that is, a certain blood cholesterol level that was as firmly associated with heart disease as was the tubercule bacillus with tuberculosis or high blood sugar with diabetes. (Garrety, 1998, p. 733-734)

Thus, underlying the discourse of many of our participants is an epistemology that the world can be mathematized in a way that makes for perfect explanations of the data (granted that they are "good" data). However, we do not claim that people actually "hold" such beliefs. Rather, even people who have never thought about these relations, drawing on cultural resources to which they are consistently exposed (such as the media), and possibly because of "common sense," will make claims that are consistent with such an epistemology. The claim that scientists believe in the isomorphism of nature and mathematics (Lynch, 1991) should be expanded to include at least those populations from which our participants originate—(future) teachers of science. But whereas scientists know from (research, laboratory) experience that data almost never fit ideal lines, our participants did not have such experiences. Thus, our explanation for the answers provided by our research participants focuses on the differences in the habitual practices in which the different participants engaged rather than in differences in cognitive ability. This contention is further elaborated in the next section which shows that even practicing scientists may experience difficulties when it comes to interpreting line graphs that do not come from their own domain.

FINDINGS II: INTERPRETING TRANSFORMED DATA

Our second research question concerned the interpretation of data when these were already expressed in the form of a graph, that is, "How do (preservice) science teachers interpret a graph from published research?" The Plant Distribution graph (Figure 3) is one which originated in the scientific journal literature, but which is also found, in a transformed fashion, in undergraduate science textbooks and lectures (Bowen & Roth, 1998a). Thus, asking participants with science backgrounds to interpret such a graph is an "authentic" activity in that it is one in which they would normally engage, as part of their reading of scientific writings, as they learned about science. This particular graph is also conceptually consistent with the Lost Field Notebook task as both deal with a correlation of two measures. However, they are also different tasks in that in the Plant Distribution task the transformed representation is already complete and has been "cleaned" so that variation is minimized and the best-fit lines are generally consistent with the caption. By adding the caption, we constructed a task that had a high degree of similarity to the ordinary activities of scientists than would using a graph without the caption. Even those participants who had little familiarity with journals inferred that the scientific literature was the source of the graph. As one preservice elementary teacher suggested, "Maybe there is an article that goes along with it where it says something about the plants being important for something or other." Furthermore, a pilot study suggested that without a caption this graph was virtually meaningless for all members of a group constituted of graduate students of education and mathematics education professors.

Semiotically-Informed Phenomenological Hermeneutic of Graphs

In research on graphs and graphing from a sociocultural perspective, we have evolved a semiotically-informed phenomenological hermeneutic to frame, describe, and explain the process of interpretation (Roth, 1996; Roth & Bowen, in press; Roth, Masciotra, & Bowen, 1998; Roth & McGinn, 1997, 1998). A phenomenological hermeneutic undertakes to rebuild, from the beginning, the conditions necessary for the understanding of graphs as cultural units which semiotics—and traditional cognitive science (e.g., Larkin & Simon, 1987; Tabachneck-Schijf, Leonardo, & Simon, 1997)—accepts as data because communication functions on the basis of them. Such an approach is necessary because our research showed that graphs, even for practicing scientists, are often highly ambiguous "things" that have to be constructed as a signifying object with particular features before or as part of constructing possible referents to which the sign refers. Phenomenology therefore refers perception back to a stage where signs are no longer confronted as explicit messages but as extremely ambiguous texts akin to aesthetic or biblical ones (Eco, 1976; Ricoeur, 1991).

[Insert Figure 7 about here]

We view the interpretation of graphs as a dual, not necessarily sequential process which (a) establishes the graph as a sign which (b) stands for some phenomenon in the world (its referent). In the first process, the graph as a sign to be constructed is an object in the world which itself has to be structured (Figure 7; top left). That is, the graph is a referent for the structuring processes that establishes its nature as sign and its specific feature. The result of the second process is a phenomenon in the world that stands as a referent to the graph as sign (Figure 7; bottom right). Our work shows that during graph interpretation, the two processes are interwoven such that both graph as object and graph as sign are concurrently constructed in a cyclic and mutually constituent fashion (Roth, 1998; Roth, Masciotra, & Bowen, 1998). Interpretants are of a different nature and can be: an equivalent sign vehicle in another semiotic system, (drawing of mountain) synonym, translation into another language ("Berg"), emotive or metaphoric association (mountain = purity), a scientific or naive definition in the same semiotic system (mountain = natural elevation with steep sides), or an iconic representation of a mountain (e.g., Fuji). The work of sign-interpretant relation is to elaborate the sign-referent relation. In this section we illustrate different levels of reading by (a) a professor who knows the type of research and the graph intimately well, (b) other scientists who know the type of research, (c) (preservice) teachers who mainly construct the graph as a signifying object and engage in literal readings, and (d) two scientists who discarded the graph as meaningless.

Readings by Scientists

We can see the effect of these different types
of metabolisms on distributions of plants

Distribution graphs are relatively familiar to most scientists. Yet reading a graph is not a straight-forward activity, and it depends on the level of familiarity with the referents of axis labels and objects identified in the graph, that is, with the dimensions that span and constitute the new (virtual) space, and on familiarity with the research methods that lead to such graphs.

For the ecology professor (Sen) familiar with the research from which the graph was taken, the graph was actually transparent such that he hardly referred to it at all, but talked about its "meaning," that is, the ecological discourse into which it inscribes itself.

We can see the effect of these different types of metabolisms on distributions of plants. Here we have a moisture and elevation gradient and a transect which is actually an

> elevation gradient but here elevation is closely associated with moisture and temperature. The low land, it's more or less desert, it's very hot and dry. You get higher up in the mountains and it's cooler and wetter. [Sen]

Here, Sen does not begin with a reading of the graph, but prefaces his description by an overall statement about the purpose of the graph. These are the kind of readings we often get when individuals thoroughly familiar with the particular topic "read" the graphs or diagrams that they are thoroughly familiar with. However, our research also shows that the same scientists who are not thoroughly familiar with a topic have to expend (sometimes tremendous) efforts to construct the meaning of a graph or, as we show below, abandon all interpretation before integrating this graph into their familiar discourses.

Sen, who has been teaching an introductory ecology course for several years, provided us with a "literal" reading of a particular aspect of the graph, the position of the distribution maxima.

> This [graphic] is just showing you the distribution of numbers of plants that have different types of metabolisms. Where it is coolest and least dry [$C3_{max}$], relatively more C3 plants. Where it is sort of intermediate here [abscissa $C4_{max}$], and intermediate temperature, intermediate dryness can have relatively more [$C4_{max}$] C4 plants. And where it is extremely hot and dry [abscissa CAM_{max}], because this is South Texas after all, we have relatively more [CAM_{max}] CAM plants. So these metabolic differences happen to have strong effects on distribution of the plants. [Sen]

This type of graph is frequently used in introductory ecology courses. For example, resource utilization along some niche parameter and specialization (adaptation) which expresses itself as population density variations along the adaptation parameter are commonly found types of distribution graphs (e.g., Ricklefs, 1990, p. 732, 752). In fact, Ricklefs (1990) shows several distributions of flora species along moisture gradients: deciduous trees along a moisture gradient in Wisconsin using "average importance values" as the ordinate dimension (p. 687); Oregon and

Arizona with a biomass measure, stems per hectare, as indicator for "importance" (p. 666); and hypothetical graphs distinguishing open and closed communities along an environmental gradient which is, in the text, exemplified in terms of a moisture gradient (p. 659). In the original article from which the Plant Distribution task was drawn (Eickmeier, 1978), photosynthetic pathways as the major means by which ecological resource (niche) division occurs in plants along a moisture gradient was the key point in its interpretation.

Thus, without much work of reading the details of the text (graph, caption), Sen provided us with a reading of the significance of this graph in the domain of his research and teaching. Rather than some cognitive aspect that distinguishes him from the other scientists, his greater familiarity with this kind of graph, and this graph in particular, is a more reasonable and simpler explanation. Our conjecture, about the importance of habitual engagement in graph interpretation in settings where it is common practice to engage in such domain-specific activities, gains increasing importance as we provide our analyses of the other practicing scientists, and in particular those who found the Distribution Graph meaningless and difficult to interpret.

Reading the Distribution Graph

For scientists who were less (or not) familiar with the topic (photosynthesis), domain (botany), or research methodology (transects), interpreting the graph was a more protracted effort.

> Here [abscissa] is your elevation. So you're taking some kind of a transect that goes up the mountains. And down in the valley you have warm dry climate and as you go higher you're getting cooler temperatures and a little of precipitation and cloud formation and as a result something is zoning itself out. [Sid]

In the first structuring move the abscissa is made salient. At this point, the graph is characterized by an abscissa with the particular feature of having elevation as a referent. In his next move, Sid found a referent in the world (of his experience), the abscissa standing for a worldly situation where making transects by sampling along some geographic parameter is done. Sid drew directly on his experience, which includes collecting samples in oceans, of some phenomenon distributed both horizontally (geographical distribution) and vertically (depth distribution). Furthermore, as he described the transect moving up the mountain or down into the valley, he also associated these with the experience of changing "climates" associated with such moves.

In the same way, Sam invoked the changing climes and fauna that can be directly experienced on the West Coast, or on any trip into the Rocky Mountains, Alps, or other mountain ranges. Ira (an "Instructor") talked about a trip across Mount Kenya from semi-arid plains on one side through plantations of coffee into the cool mist, and Sid articulated a zonation of those things to which the distributions refer. In Vancouver (Canada), for example, both zonation and climate differences are visible during many parts of the year when there are barren, snow covered peaks on the mountains and blooming, even exotic plants in the low lands. Here, the salience of elevation was used to construct vivid images and descriptions of natural settings. Scientists make sense, that is, link the representation with their other understandings and experiences ("so it, just as you go up it gets colder and wetter, that makes sense" [Sally]). In this case, "sense" to Sally meant that there is a preservation of the structural properties of the graph in which the graph can be read as indicating higher = wetter and cooler—which is consistent with her experience.

> So, it's showing some kind of zonation that whatever C3 is it likes, it dominates at these higher altitudes, C3, it's kind of, it's a minimum and it actually picks up down at the bottom. So, there's a bi-modal distribution in this. That's CAM that may have a zone in the middle, on the upslope where it reaches a maximum and doesn't grow anywhere else, or doesn't live anywhere else. And C4 is a weakly bi-modal, it has a peak there [left] and a major peak [$C4_{max}$] there so you'd find C4 dominating, well not dominating because C3 is dominating but it's relatively high at mid elevations. [Sid]

Here, Sid constructs the graph as an object which can refer to something else. He is concerned only with the particular features, the location of the various peaks and valleys with respect to the elevation, and with respect to the relative frequency. As to the latter, he distinguishes between "dominating" and being "relatively high," in which the C4 peak is contextualized and therefore relativized in two different ways. In the first, "it is not dominating" sets the C4 peak in relation to the C3 graph at the same abscissa location; in the second, the C4 peak is read relative to the other points on the C4 graph. The ecology professor (Sen) who was familiar with the research that had led to the graph never entered this stage of the interpretation.

> OK, so they "predominate in the hottest, driest environment" but why they drop off at the hot, why they didn't go up there, that's a question I have about it. [Sid]

Here, the opposite to making "sense" occurs. At this point, the graph appears to be inconsistent with the caption text which indicates "predominates in the hottest driest environment" whereas the graph shows a drop in the relative importance. Sid appeared to say, "I cannot make sense of this feature of the graph," that is, he could not integrate it into what he already knew or what the other parts of the text (graph, caption) told him. Testing consistency did not only move from graph to experience or inference, but also the other way around. Sally first suggested, "I assume these things [C3, C4, CAM] don't all live at the same level?" but then rejected that assumption as she inspected the graph which showed values unequal to zero for each of the graphs ("these guys are actually all existing at each of these elevations. It must be, obviously").

> I guess CAM are succulents. . . they are obviously very good at holding moisture. I mean, plants that live in hot drier areas tend to be very good at it, they've got waxy coatings on their leaves and they tend to be very good at not losing moisture when they are exchanging gas. Oh, so these guys actually have a nocturnal gas exchange for water preservation, oh cool, okay. [Sally]

Although Sally did not know about the photosynthetic mechanism and how it operated in the course of the day, she constructed from what she knew (waxy coatings) and what she read in the caption (nocturnal gas exchange) to construct a story that made sense to her.

Sid concluded with a statement about the adaptation of the plants which allow them to compete relative to other plants, or to succeed in particular climes, "So each one of these plants has adapted some strategy to succeed over other plants or succeed in a particular temperature and moisture domain" (Sid). Similarly, Sally also concludes discussing the plants adaptiveness to the climate in which they're found.

> I don't know what kind of plants these guys would be, I would presume they possess some, I guess, it's not clear to what, what sort of adaptation these guys [C4] would have, but these guys [$C3_{max}$] are probably adapted, what's 2000 meters, that's fairly high, so they're probably adapted so much to that higher elevation, certainly accustomed to a lot more moisture. [Sally]

The scientists ended with explicit statements about the adaptation. These statements arose from the scientists' attempts to explain the contrast between the three curves associated with the three photosynthetic mechanisms. One scientist (physicist) made direct links to C3 plants as possibly being grasses or conifers, or other Alpine flowers, the kind of plants he knew from experience grow at high elevations.

The "discrepancy" that C3 and C4 plants increased in relative importance at very low elevation levels was not necessarily a salient element in scientists' interpretation. Some scientists and the instructor noted them but did not address them at all (Sid). For example, Sam suggested that, possibly, the gradients of moisture and temperature indicated at the top of the graph may not hold at the lowest elevations or that a lake or ground water levels provided the moisture to which C3 and C4 plants were adapted therefore displacing the CAM plants.

> If you see relative abundance, then you add it up probably to something like a 100. These are not independent, the three curves. Like you don't have, you don't have something like density that's plotted. Then, but if you get a peak here, you necessarily get depths in the other. [Sam]

Sally, too, noted that the three graphs were not independent and suggested that the graph was not a good plot and that "it would be a lot better to plot a straight out density or biomass or something like that, or just whatever, straight numbers, whatever you wanted to represent."

Analysis

The scientists who read the graphical representation in this way did three dimensions of reading work. First, they read the lines in terms of their past experiences relating to a changing fauna with elevation and associated climatic changes. At the same time, they locate the three distributions with respect to each other. Finally, they attempted to explain the location of the three maxima in respect to each other by drawing on the concept of adaptation of plants to the physical environments. Their analytic work carved the reality of the graph such that each of the three relations told a story about the relative frequency of a type of plant (even if they did not know what type of plant it might be). The other dimension of their work was the relation of the text to some state in the world. First, this state is about the relationship between the frequency of one type of plant with changing elevation (or climate). In the second instance, the state has to do with the existence of ecological niches.

Instructors & Preservice Teachers

We're just trying to determine what was the purpose
of this graph beside showing distribution

The interpretation sessions of three instructors and four pairs of preservice elementary science teachers were characterized by their predominant focus on the nature of the graph (and almost non-existant discussion of referents in the world). Their readings were largely literal rather than being concerned with the implications of the contrast raised by the three graphs. One preservice elementary teacher's comment at the end of their interpretation, "Because all this does is tell us where these 3 points are" (Etta) in a way summarizes what these individuals and groups concluded about the distribution graph. The fifth group of preservice elementary science teachers differed somewhat because, in a manner similar to that of scientists, they attempted to link the distribution graphs to their experiences in the desert, on mountains, and in different parts of the US. A secondary teacher summarized his analysis in a similar way:

> All I can say here is relative importance whatever that's supposed to mean here for the C4 type plant, it never gets all that high at whatever elevation, the highest it gets to whatever 30 something that's supposed to be, at around 1, 2, 3, 4, 5, about 1400 meters, the CAM one varies greatly, it's much lower at the higher, jumps up to its maximum at around 800. So, I can give you some numbers, I was not entirely sure what they mean by relative importance. (Ian)

As a result, the participants did not feel particularly successful at the completion of the task. Eva suggested "If I came across this in a textbook, I would likely just skirt right by" and Eldon commented "Relative importance, I didn't get that part"

The following episode was recorded five minutes into Erica and Eliza's 27-minute session with this graph. At this point, they attempt to establish the relevance of some basic graphical features such as the additional abscissa above the graphs:

Erica: But look, it was relative importance, 40, 80 does it say anything about that?

Eliza: This is just a XY graph, not XYZ or anything, it seems strange that there's three [top abscissa], I don't know about X

Erica: Like, you know what I mean, there is this [abscissa] and this [ordinate], you know, and there is also that [top abscissa]

Eliza: Yeah, but this [top abscissa] is just READS[caption] desert and semi-desert, but it seems.

Erica: So we can even ignore that [top abscissa]? I mean, and just go according to this [ordinate] [abscissa]? But the thing is. (10 s)

Eliza: Relative importance. Well it's a distribution along a moisture and temperature gradient due to differences in elevation. So <u>this</u> [upper abscissa] corresponds with elevation, it's hottest, right? It's hottest and driest at 500 [500] and as you get to an elevation

Erica: OK, so that's what it is all about?

Eliza: At 2000 meters it becomes coolest and least dry because they say C3 predominate [$C3_{max}$] at the cooler, least dry end [upper abscissa, $C3_{max}$], that's what they're telling us.

Eliza and Erica attempted to integrate ("make sense of") the graphical representation—particularly the secondary abscissa indicating climatic gradients associated with the elevation gradient—with the discourses about x-y and x-y-z graphs with which they were somewhat more familiar. For example, in their first reading, they treated the correlative abscissa as a different, third dimension as it would appear in an x-y-z graph. Erica asked whether they could ignore the secondary abscissa and interpret the graph as a relation between elevation and relative importance. However, having re-read the caption, Eliza pointed out that the upper abscissa is simply correlative to the lower one and made explicit links between the elevation scale and the temperature-moisture scales (e.g., 500 m hottest/driest, 2000 meters coolest/least dry). What is remarkable about the episode is that neither Erica nor Eliza attempted to link their statements about the relations in the text (graph, caption) to their personal experience or other referents in the world that might have helped them to make sense (establish structural equivalence) and therefore increase their understanding both of the graph and the world.

Erin: READS["C4 plants are maximally important under intermediate temperature and moisture conditions."] So, intermediate and moisture, like what I would say is that the hottest and driest is going to be at that elevation?

Etta: Well, it is because, oh well just because it says that, it doesn't mean that this is the hottest and driest that's possible on planet earth (Erin: No) It just happens to be that this is hottest and driest compared to this over here, so it appears on this section right here.

Erin and Etta struggle for meaning at every step of their analysis, that is, try finding in their own experience discourses that would help them elaborate the text (graph, co-text) in front of them. In the following episode, Eldon and Eva attempt to relate the elevation (lower abscissa) and the climate variables (upper abscissa):

Eldon: Least dry. So that must, yeah, so least dry over here [$C3_{max}$], so it's cool there

Eva: I think that this is what is confusing. Like I get that [$C3_{max}$] this highest point [CAM_{max}] just when [$C4_{max}$] it's best at photosynthesis and then this [left, upper abscissa] is hottest, driest, coolest [right, upper abscissa], least dry. Then this elevation [500 m], like in my thinking lower elevation would mean, I guess not, I was thinking cooler, colder, and then higher [2000 m] elevation would be warmer.

Here, even relating the two gradients in the context of the caption appeared troublesome. Eva, who had read the caption which indicated that C3 plants do best in a cool wet climate, had trouble with her association of coolest and least dry with lower elevation. Each aspect that they identified could therefore not be taken as granted but had to be integrated with the other pieces of the graph (cum caption). In the same way, Erna struggled with connecting the ordinate construct (relative importance) and its scale to something she was familiar with:

> But here, I mean, how do you connect this thing at 40 and 80, do you see this as a percent, or do you see, what do you see? These 40 mean, can it mean something? You know what I mean, like without just looking at these 'cause these correlate right, these 500 mean hottest and like that but here. [Erna]

In the process, she attributes "hottest" to an elevation measure (500), rather than constructing the relationship as an association. In part, these student groups struggled with what appeared to them to be arbitrary associations which, in the readings of scientists, were immediately meaningful through the association with their personal experience in relevant environmental settings. Thus, although the preservice elementary science teachers found themselves in the same situation as many of the scientists (i.e., not knowing about this aspect of ecology) the preservice elementary science teachers appeared to struggle with each element, the meaning of each process (CAM, C3, C4), whether these labels stood for individual plants, types of plants, or processes, what the referent of "relative importance" might be, and so forth.

Another reason that difficulties arose in interpretation of graphs was because of the interpretation of words in non-canonical ways. "What I was thinking is that, the importance of the C3 being at coolest, least dry at 2000, it's very important that it would occur there, you know what I mean?" (Erna). "I'm not understanding what relative importance means (pause)? I guess, important to the environment, or what?" (Erin) "This photosynthesis process which occurs in this C3 plant is not so important, there might be other processes which occur," and "the importance of it occurring at this elevation at this dry." The difficulty with interpretation of what the ordinal axis label "relative importance" meant contributed to difficulties encountered interpreting the graph.

Although the conversations among the preservice elementary science teachers and science instructors generally did not elaborate on worldly referents, we already described in the previous section that Irá began his session by referring to his experience of hiking up and down Mount Kenya, and the changing climates and flora associated with this trip. There was also one group which, to a much lesser extent, attempted to link the graphical representation to places they had already visited. Also in the following quote is an example of participants reaching conclusions which, although not necessarily incorrect, were not relevant to the biology of the plants in the problem at hand. Here, Eli linked "thinner air/ atmosphere" with lower moisture levels, a fact that contradicted what he had read from the graph and caption.

Eli: I think of elevation as well, you go up higher there is less, there's thinner air, thinner atmosphere means generally less moisture because there's less air, so there would be less water in the air. It's harder to breath the higher you go up, because there's thinner air, it would mean less (Ella: Less moisture?) Yeah it's true, there is snow up there, but it is pretty frozen, I don't know if that counts as moisture, I don't know, it might. I guess it precipitates, it's snow, but it's snow moisture.

Ella: Well, the further north you go in Canada, the climate is generally quite dry so I guess, in those terms, but the elevation is not that high.

Eli: But this is Texas too, which is just generally warm. I've not gone, I've been to California, I haven't been to Texas, I've been to the central area of the States, yeah, or the eastern part of it.

Before that, Ella had already talked about a visit to the Californian desert and her experience of the large temperature variations and the relative dryness; she furthermore noted that cacti had to be well adapted to such a climate. But neither she nor her partner generalized the adaptation argument to the other types of plants described in the caption and to the graph as a whole.

Although the discourse in these groups generally stayed within the context provided by the graph/caption, there were three brief instances in which comments addressed issues of adaptation and survival. Yet, every time, the significance of these issues was never pursued or became salient; they generally appeared as passing comments and remained unelaborated and little connected to the interpretive task.

> But the thing is if you look at it, none of them are at the same elevation, so they all predominate too at different elevations which allows better survival as well. Because they're not fighting for area and they're not fighting for the resources in that area. [Erin]

> It just looks like you have three different plants, each photosynthesis method makes it more suitable for different environments, so as you could, go through the gradient, you get different plant populations predominating. [Ed]

These comments were the only ones in the entire sequence related to the Distribution Graph in 1596- and 749-word sessions, respectively. These were not culminating comments that summarized the activities, but were strewn in the middle of their talk about the nature of the graphs.

Other Scientists' Interpretations

I knew that it wasn't very meaningful, it was just trying to show visual patterns that were detached from reality

Two of the scientists refused to engage in a school-like activity and critiqued the graph from the perspective of their own work. In both cases though, they provided nearly transparent readings of their own graphs which had appeared in research journals and reports (Roth, Masciotra, & Bowen, 1998). Both provided us information at the end of the interview or sent us information afterward on how to prepare better graphs than the ones we had used in the research with them.

> I knew that it wasn't very meaningful, it was just trying to show visual patterns that were detached from reality. But when I see this sort of thing here, it's important to me to understand what the scales are so I can read. Because this is in theory something that is very real, so they draw a lot of these [abscissa] scales. I look at this and I can sort of forgive it because there's absolutely *no* information at all about, you need sort of far more explanation. [Sandy]

It is evident that their difficulties have to be taken seriously. Both were successful in their professional domains and had a considerable numbers of publications. In their explanations of graphs which they had constructed for publication purposes, the graphs were actually transparent, individual features which offered them occasions to develop thick descriptions rich in detail about the contexts in which the data were collected. Yet with the unfamiliar graphs they struggled considerably and abandoned efforts of making sense.[1] The following excerpt in which Soren (M.Sc., forestry) wrestles with the "meaningless" acronyms C3, C4, and CAM illustrates this struggle.

[1] During our interviews, there were three other graphs in addition to the Plant Distribution graph (Roth, Masciotra, & Bowen, 1998): birth and death rates as function of population size; graphical representations of essential, substitutable, and complementary resources in the form of isographs; isobologram representing the effect of two resources for plant growth.

> I mean, because you've got, you're talking about relative importance, you've got 3 different species here or whatever. Are you talking about the relative importance of this one [C4] to these other ones [C3, CAM]? Or to some other external influences? I don't know. [Soren]

Sandy (Ph.D., marine biology) similarly attempted to come to grips with the notion of "relative importance." Both scientists struggled with the fact that they neither understood nor could relate to the ordinate label, "relative importance" and that they did not know what the acronyms C3 and C4 stood for. Although Sandy realized that the graphs were to tell a "bigger message," he, as Soren, did not provide readings in the way the other scientists did.

Discussion of Plant Distribution Graph

On this task, the split between scientists and (preservice) teachers was not as clear as on the Lost Field Notebook. Two scientists found the graphs meaningless and did not provide an interpretation. Most of the preservice and inservice teachers engaged in the construction of the graph as a sign (Figure 7, upper left) and in reading the individual curves literally, that is, as a change in the distribution of a particular plant type. They predominantly read the graphs in their relation to the abscissa (i.e., noting that there are changes of the relative importance with elevation) This is what one would have expected from the Lost Field Notebook. One of the instructors and eight scientists contrasted the different curves and therefore constructed a phenomenon that was not literally available in the graphical representation: the differential adaptation of plants with different photosynthetic mechanisms to climate. In the process of reading, the scientists drew on past experiences related to the research method that yields data as those presented and on their familiarity with questions of adaptation to construct their reading of *this* graph. The phenomenon emerged from the mutually constitutive reading of graph and constructing the elements of the graph on the basis of familiar experiences. Finally, in the interpretation of the ecology professor who used this and similar graphs in his lecture, the graph as representation became transparent. He talked about the phenomenon of adaptation and how it led to different distribution of plant types in varying climates.

Thus, we can see differences where our (preservice) teachers focused on reading the lines and indicating what relationship they express. The scientists contrasted the lines and constructed a secondary text in which the relative position of the lines had to be explained. There was one student group and one instructor who actively used past experience (trip to California desert, Southeastern and Central USA; across Mount Kenya) to enhance their grasp of the Distribution graph, that is, to increase the linkage between this previously unknown text and other texts that they are familiar with from scientific and experiential domains of their Self, but it was uncommon.

The difference was further observable in the scientists' greater tendency to draw on personal experience (strip sampling, constructing transects, traveling up mountains) as an important aspect of making meaning, that is, constructing links between extant experience and understandings of the new graph. In this, they could test whether some relation they inferred from the graph "makes sense," that is, is consistent with another aspect of their experience/understanding.

FINDINGS III: DATA COLLECTION, TRANSFORMATION AND INTERPRETATION

The previous two sections dealt with practices of interpretation which required a transformation of a data set (the LFN problem) or of data that had already been transformed (the Plant Distribution graph). In both cases, data and graph were ready-made and the tasks could therefore be critiqued as more school-like rather than authentic (Lave, 1992; Roth, 1996). In the conduct of science research there are several practices which precede these representations, their transformation, and their interpretation—question "asking," operationalization of variables, and collection of data. In the past we have attributed that difficulty in interpreting graphs to a lack of experience in conducting these initial stages of research by the interpreter.

The conduct of effective research has several critical features which must be attended to and if students in public schools are to be expected to be able to do this type of analysis it is not unreasonable to expect that their teachers can engage in these same practices themselves so that they can best scaffold the children into and through these activities. Scientific research proceeds from the asking of "do-able" questions (Fujimura, 1987). These questions must have variables "identified" which must then be operationalized so that data can be collected. Various representations/transformations of the data then occur and from these claims are made which, generally, refer to the original questions asked.[2] The following analysis structures and orders the questions, design, representations, transformations and claims made by secondary pre-service science teachers (with science degrees) in their research project reports, highlighting the approaches used in each area and points at where there are inconsistencies in the chain of argument between one section and the previous section(s).

Analysis of Preservice Secondary Teachers' Reports

To aid our analysis and interpretation of the work done in the reports, we used the following analytic frame to examine and interpret how closely the reports of the Pre-Service teachers paralleled those of "typical" scientific reports. Generally, this frame evaluated competence in conducting and reporting research as this relates to the stages evident in the epistemological vee that the pre-service secondary teachers used. In our analysis, we evaluated the projects submitted using the following set of questions: (a) What is the nature of the questions? (Correlational, relational, causal); (b) Are the constructs and variables operationalized effectively?; (c) How are data represented (e.g., tables)?; (d) What data transformation techniques have been used (e.g., graphical inscriptions)?; (e) What interpretations of the data are made?; (f) Are consecutive steps in the inquiry (a through e) consistent with each other?, and (g) Do the interpretations address the focus questions?

[2] Various authors have pointed out that the written outcomes of a scientific study may result in questions being presented as if they were the ones originally asked, although they developed post hoc as the study progressed, or even in the formal interpretative stage when the actual research was concluded. Regardless, a scientific study is generally written about in a manner which gives the appearance of internal consistency and coherency from the original framing of the "question" to the "claims" about that question.

A cursory examination of the preservice secondary teachers' reports suggests that they contain the fundamental components of scientific research reports: questions, data tables, graphs, interpretations and claims/implications are generally all present—as one might expect them to be given that the epistemological vee provides prompts for these elements to be included.

To examine these reports in greater detail we independently viewed the reports and coded them into the representation seen in Table 6. Each student report was summarized in the table by highlighting (i) what type of question was being asked (Column 1), (ii) what the variables were (Column 1), (iii) how the variables were operationalized (Column 2), (iv) how the data were represented (i.e., maps and tables; Column 3), (v) what transformations were used (Column 4) and, (vi) what claims were made (Column 5). As well, symbols were used on the table to indicate when variables weren't measured in such a way that they could be compared, when transformations didn't relate to the original questions, when inappropriate graphs were used, and when claims did not relate either to the data or to the original question. Our closer analysis revealed that in the details of the research work there were many instances of non-standard approaches to the research and inconsistencies in the analysis of the data (Table 6 details ninety such problems). Generally, there were: research questions unanswerable by the study design, constructs inappropriately operationalized, data reported and transformations (graphs) used inappropriately, and claims which frequently did not match research questions or the data reported. Table 6 was ordered so that reports with the scientifically most acceptable practices and interpretations of data were at the top and those with the fewest at the bottom. We first summarize the findings and then use a representative student report from the top, middle, and bottom third of the table which we elaborate in detail to examine the use of various scientific practices in the field projects and the internal consistency of the reports.

[Insert Table 6 about here]

Structuring Research Questions - Design Issues

When the pre-service secondary teachers first entered the research area (located in "undeveloped" mixed forest at the edge of the university property) there was considerable discussion in the student pairs about what "do-able" questions they were to investigate. As students continued to work on identifying the area in which they were going to conduct their research work, staking out boundaries, and drawing a map of the zone, they started formulating specific questions to address as they noticed more and more specific details of the zone and reflected about the equipment which had been made available to them.[3]

Many of the investigations were framed as "causal" investigations—of the twenty-four questions addressed by the students fourteen were causal. For example, some of the causal questions asked were, "How does the moisture level affect the distribution and height of horsetails in our investigative site?" (Table 6, Question 3.b.) and "Do the exhaust gases from the cars parking in Lot C directly effect concentration of field flowers in front of the lot?" (Table 6, Question 11.a.). In the first case, two components of the question indicate that it is intended to address causal relationships. Firstly, asking "how" indicates causality and, secondly, assuming the directionality that it is the moisture which affects the horsetails, not the horsetails affecting the moisture level (as is the case in some plant species), indicates that the intent of the question is causal not correlational. The second example is also clearly causal in intent because of the directionality implicit in the question as field flowers could not affect the release of "exhaust gases from the cars" but the exhaust gases might affect the field flowers. Note that for both questions it is not that directionality/causality can not be demonstrable, but that the temporal structure of the activity (two field periods within 8 days) make a causal investigation unfeasible.

Operationalization of Variables

Being able to appropriately/defensibly operationalize variables in a study is a key step to being able to construct claims from the data collected. If variables are poorly operationalized,

[3] In this, their discourse was similar to that of the grade eight students we observed work on similar field-based science activities (Roth, 1996; Roth & Bowen, 1993, 1995). For the field-based activity in the present study, the preservice teachers had the same equipment available as that used by the grade 8 students in the earlier study.

then it is usually impossible to make claims that relate back to the original focus question(s). Of the student reports, several (seven of twelve) studies had problems with how they operationalized their variables and/or with replication or sampling (Table 6; second column). In part, this was the result of addressing questions which were difficult to operationalize involving, as they did, biological factors such as "competition," "biodiversity," or "productivity" that are ecologically quite complex (and abstract)and which often require long-term studies and data collection. However, problems with operationalization of variables also occurred in situations where these conditions were not present in such a way that they would interfere with effective operationalization.

An example of effective operationalization of variables is found in the first study (Table 6; Questions 1.a. & 1.b.). In this study, to address the questions, "Do spittle bugs show host preferences for three dominant plants in the plot?" and "Is there a relationship between light intensity and the distribution of [plant species] in the plot?" the preservice secondary teachers: (i) identified locations of individual plants of the three species; (ii) counted the number of spittlebugs on "ten stalks of each plant at five randomly chosen sample sites"; (iii) graphed the average number of spittle bugs found (with error bars) for each type of plant; (iv) measured light intensity in a grid across the entire mapped area; (v) drew a pattern map with the light intensity indicated over which was laid the locations of the [plant species]; and (vi) made claims related to the original focus questions using the data set collected and depicted in (i) to (v). This sequence effectively operationalized the originally stated focus question.

In conducting our analyses, we decided to highlight instances of problems with operationalization which were apart from those of causality being inappropriately addressed (indicated in the previous section). Two major types of problems with operationalization were highlighted: (i) the measured variable ineffectively reflected the conceptual intent of the initial question, and (ii) there was insufficient replication or an inappropriate sampling regime.

One particular study will be used to illustrate both of these situations. This study (Table 6, Question 12.a. & 12.b.) addressed the questions, "How does the side of a fallen log affect it's biodiversity?" and "How do the burned portions and the recent and older exposure of new wood affect the snags biodiversity?" To address both questions "biodiversity" was operationalized as the "frequency/quantity" of different types of organisms—lichen, moss; small plant growth (non-lichen, moss); spiders; beetles, larvae; and insects. Counts for lichen and moss in different areas were indicated as whole numbers ranging from one to five; no indication was made as to whether this enumeration indicated patches of the plants or individual plants (which, given the setting, is highly unlikely) or how this related to patch size. In this study, a count of "2" insects in a section represents large (macroscopic) insects visible at the surface, not those beneath the surface of the soil, under plants, in logs, etc. In this case, insufficient operationalization and sampling meant that even correlational claims based on data as it was presented would be inappropriate.

Representing Data

Data was represented or depicted in the reports in two main ways: in "maps" (which were requested as part of the assignment) and in tables. All reports included a map representation and 14 of the 24 focus questions had data summarized in a table. Several of these tables were structured in non-standard ways and did not aid in understanding any patterns that may have been interpretable in the data. For the reports that did not use a table, using a table would have aided interpretation. Indeed, for the questions that were being addressed, using a data table in the collection process might well have led to more effective data collection. Our ethnographic field work with ecologists highlighted the role that tables served in their work—less as a representation tool than as one which "reminded" them what data they needed to collect (Roth & Bowen, 1998). In the practice of field science, tables serve as a tool which organizes researchers' thinking towards the focus questions and what data needs to be collected. Observations made of students in their lab activities during this course suggested that they viewed tables as a representation/presentation tool and not as an integral part of organizing the research before and as it was being collected.

The maps in reports occasionally served as a surrogate for tables by helping the report writers relate variables. In three of the reports the maps were not sketches of the landscape upon which data sampling sites were recorded but were instead grids onto which measurements, locations of plants, or counts were recorded. Three other maps were diagrammatic sketches detailing plant locations and physical locations onto which measured data (e.g., light levels, moisture levels) were inscribed. The remaining six reports contained maps which detailed plant and substrata distributions but which were not used to indicate any measured features from the focus questions. Thus, it was not possible to use them to examine relationships between the biotic and abiotic variables under study—in essence, these maps served as iconic representations, "pictures" of the site, but contributed little to the investigation of relations being conducted.

Transforming Data: Using Graphical Inscriptions

Use of graphical representations occurred in almost all of the reports (10 of the 12; one of those that did not may have been able to more effectively interpret their data if they had). However, there were many problems with how graphs were used in the reports to depict the collected data. One report used line graphs when bar graphs would have been more appropriate for the data, three reports used bar graphs when scatter plots were more appropriate, and one report used a one-dimensional bar graph when a 2x3 bar graph would have better illustrated the data set. In one case, further insight would have been gained if an X-Y-Z plot had been used. Even when scatter plots were used (five times), best-fit lines were drawn on only two of them, and in one case was placed incorrectly. An outlier, which might significantly affect interpretation, was noted in only one case, although in the previous example (of the trend line being misplaced) identifying an outlier would have affected interpretation of the graph.

Apart from the broader concerns of appropriateness of representation, graphs were often labeled or structured in ways that confounded their interpretation by the readers and were often inadequately (or not) discussed in the text of the report. For instance, one graphical representation depicted "gradient" and "change in moisture" on its axes, but was not referred to in the text of the report nor discussed in the "methods" section and was therefore lacking interpretive context.

In several student projects labeling of the maps, tables, and graphs was such that they contributed little to understanding what these inscriptions were representing. As a result, readers had to spend considerable time trying to relate written "claims" to the various inscriptions in an attempt to understand how the claims were derived. This lies in contrast to typical writings of science in which there are clear cues and pointers between report text, captions, and labels which together help the reader constitute and construct for themselves the claims from the data which is being presented. Understanding derives from reflexively cycling back and forth between the text and the inscriptions relating those pointers to ones own experiences. As labels, titles, and text become impoverished so too, subsequently, does the understandings which readers derive from them.

Four graphs were drawn which were unrelated to the questions being addressed, and in some instances there appeared no conceptual reason to construct some of the graphs (such as plotting a bar graph of averages of measures across a slope). In total, 6 of the 10 reports using graphs[4] had problems with how they used graphical representations to depict the collected data with a subsequent effect on the claims drawn from those representations (Table 6).

Interpreting Research Data

The conclusion of a scientific report attempts to draw conclusions about patterns in the data collected/represented and discusses data in the context of the original question(s). This is often followed by a discussion of implications of the data, any issues arising from the design of the study being reported on, and future questions which might be addressed. The epistemological vee prompted the preservice secondary teachers both to include graphs and interpretations of those inscriptions in the analysis of their data. In our constructive critique of the claims section

[4] Whether it was appropriate (in our view) to utilize a graphical depiction for a particular data set when one was not used was not a consideration in this critique. The total was derived from conceptual issues arising from graph usage—not part of this total was any critique of structural difficulties such as poorly labelled axes, poor titling, or non-discussion of the graph in the text.

of the reports we therefore focus on the interpretations of the data being reported on (both graphs and tables) and how these interpretations relate to the original question(s). Our analysis examines the graphical representations and analyses used to report on students' own research work in contrast with analyses of the Lost Field Notebook and Plant Distribution graphs.

Several of the reports had interpretations which clearly followed from the collected data and its representations and transformations. However, many other of the reports made claims unrelated to the original question(s) or which did not logically extend from the data collected/depicted. Of these, the latter is the most problematic and occurred in ten of the twelve reports (Table 6), in some reports with regards to one claim, in others with regard to all of the claims made.[5] Also, in five of the reports, claims were made which were not related to the original question. For example, one report concluded that "intraspecific and interspecific competition affects the growth, density, and distribution of plants" drawing this causal conclusion from a dataset lacking measures attributable to "competition" (a quite abstract ecological concept) or of "growth." However, in only two cases was this done and the original question also not addressed (in two other cases no claims were made related to a question posed in the study at all). No statistics were calculated in any of the cases nor was mention made that they could be calculated for the correlational data. Overall, problems with the claims' sections arose more frequently from claims made which did not extend from the collected data, a quite frequent problem, rather than from claims which did not address the original question.

Detailed Analysis of Three Cases

To gain further insight into the competencies of the pre-service secondary teachers holding science degrees in standard scientific investigations we conducted a micro-analysis of three of the reports. In this analysis we examined the structure of the questions, the recording and

[5] Errors were not "double counted" in our analysis. For instance, if "slope" was operationalized inappropriately for the scientific meaning of the term and indicated as such in column 2 of Table 6, the interpretation of slope data in the claims section was viewed as being "inconsistent"or "consistent" in relation to the data which was collected, not in relation to a correct operationalization of "slope."

reporting strategies, and the final claims for internal consistency and the methodological approaches used using the analytic frame detailed above. Table 6 is ordered such that reports with the most canonical approaches to research and reporting are found at the top and those with the fewest at the bottom. For this micro-analysis we chose one report from near the top, one report from the middle, and one report from the bottom of Table 6. These reports ranged from one that asked correlative questions, operationalized variables effectively, represented the data effectively, and drew claims related to the original data to a report which addressed causal questions, inappropriately operationalized variables, used inappropriate representations (of the collected data) and drew inappropriate conclusions (from the collected data).

Case # 1 (Table 6; Questions 2.a. & 2.b.)

This report addressed the focus questions, "Is there a relationship between the maximum height of the horsetails and the density of the horsetails?" and "Is there a relationship between the maximum height of the horsetails and soil moisture?" To answer these questions, students staked out a 4 m by 5 m area with string in 1-metre square sections and drew a detailed map of its plant biota. Moisture was determined by repeated measures in each 1-metre quadrant to the "depth of the horsetails' tap root." Horsetails were "counted in each quadrant" and the height of the "horsetails in each quadrant was determined and recorded." (Details of data presentation and interpretations are found in Figure 8.)

[Insert Figure 8 about here]

In our reading of the report we noted that both questions addressed correlations and were answerable in the physical and temporal context within which the students worked. The operationalization of the variables was consistent with the original questions (i.e., the questions dealt with horsetail height and density and soil moisture, and these were the data collected and tabulated). Data were inspected and one set of plants excluded from analysis as it appeared to the participants that they were misclassified and would thus confound or mislead interpretation.

This report used two Cartesian graphs (Figure 8b & 8c) which allowed answering the focus questions. What lacked in these graphical inscriptions, in comparison to the work of practicing scientists we observed during and after this fieldwork, were lines of best fit and statistical evaluations of the relationships. Conducting linear regression analysis would have revealed that the linear relationship between height moisture had a regression with $r = .75$, $p < .008$ and the linear relationship between height and density had a regression with $r = .65$, $p = .023$. This analysis was not done (which is not unreasonable since statistical analysis was not requested in the assignment), however, if it had been it would have strengthened the final claims (Table 7) made in the report. The first claim pertains to the original question asked, yet the speculation as to the correlation between height and density appears is not the only one possible. The second claim is a reasonable inference because high transpiration from some plants can lower local moisture levels.[6] Though the report does not discuss these explicitly, some of the "additional questions" (e.g., "how soil type affects soil moisture") allow the inference that the reports authors were considering these issues. Overall, this report showed a strong internal coherency, such as is found in formal scientific documents, from the original questions which were framed to the claims which were drawn from the data.

Case # 2 (Table 6; Questions 7.a. & 7.b.)

This report addressed the focus questions: "How is moisture related to the slope of the hill?" and, "Is the clustering of the ferns related to the moisture in the soil?" To address them the students marked out a 4 m by 5 m plot and "drew a scale map of the plot including plant types and location" and then "divided plot into 20-1m^2 sections." They then "took moisture readings in every corner and the center of each section, at 4 cm depths." "Slope" was operationalized by

[6] Another reasonable interpretation from a biological perspective would have been that favorable conditions allow both increased distribution/height and density which therefore covary without having to be the cause of one another.

measuring distance down the slope from the highest elevation of the marked out plot. (Details of data presentation and interpretations are found in Figure 9. Letters A - E represent cross-slope co-ordinates, numbers 1 - 4 represent down slope co-ordinates.)

[Insert Figure 9 about here]

The questions in this report are structured to examine the relationships between two variables are ineffectively operationalized and the data sets not juxtaposed so that these relations can be determined. "Moisture" was operationalized as 'average soil moisture,' slope as 'distance down slope,' and fern counts or density not determined or represented in ways which allowed comparison to the independent variable of moisture. Observations such as the locations of plant species were recorded in a scale map (represented in part by Figure 9, Data (a); No key was provided) which could have been used for comparison with the measurements of average soil moisture in each of the 20 quadrants (Figure 9, Data b).[7] One characteristic of traditional science practices found in this study was the replication of measures of moisture reported in Data b.

Data was then transformed into the representations seen in Figure 9: Transformed Data 'a' & 'b.'[8] The Transformed Data 'a' bar graph represents the average moisture in the five sample strips (each with 4-1m^2 plots) across the slope. This bar graph is neither discussed in the text of the report nor does it address any of the questions being addressed thus there seems little theoretical reason for its inclusion. The figure shown as Transformed Data "b" represents the average moisture "down" the slope of the plot. We asked two ecologists to examine the graphs and they noted that because of the "relationship" that was initially framed as a question they would have chosen a Cartesian x-y graph to represent the data.

[7] The data in Figure 9, Data c which, being unlabelled and unreferenced in the text, was at first not interpretable. After some work, we realized that Data c represented the average of the moisture readings obtained in each quadrant which were given as raw data in the table shown (in partial representation) in Data b.

[8] Neither of these representations are explicitly related to the "slope of the hill" focus question (bar graphs are not used to illustrate correlations; although such a relationship may be read into Transformed Data b), and neither are related to the second focus question.

To address the second question our ecologists said they would have plotted the values of all measurements of moisture, or at least the average from each of the 20 plots, in a scatterplot with fern counts in each quadrant. However, such a graph may not have been possible (from the data included in the report) because there was no measure of fern density at the field site other than that in the site map that was drawn. If this map were "to scale" (as the report indicates) and the "F" markings indicated individual fern plants (this was not explicated) then such a graph was possible to construct. Finally, the bar graphs, which depicted means of means did not include error bars to indicate the standard error although these were calculable from the data available. As indicated in Figure 9, there was little labeling of the figures and no captions were provided (which complicated our interpretive analysis of the inscriptions).

The report's first claim (Table 7) was stated as a "relation" (top, middle, bottom) as opposed to the correlational framing of the original question. A statistical analysis of the correlation from Data c, suggested to be a normative approach by our field ethnography work with ecologists, shows a correlation coefficient of $r = .66, p = .0014$; F tests for the four distance categories would yield $F = 7.01, p < .004$)). Hence, the report understates the conclusion which can be drawn from the data which was collected.

The report's second claim, that "pattern of fern placement on the slope is not related to moisture content of the soil," is difficult to interpret because, other than the visual clues which can be taken from the scale map regarding plant distribution, there are no numerical data to substantiate the claim. The ecologists we asked to view this report suggested that it be better to operationalize "fern placement" along the slope so that it is a quantity thereby allowing statistical estimates of Type I and Type II errors allowing the claims to be situated. Finally, the text of the interpretations/claims were unelaborated providing little guidance as to how the graphs and information in the report should be read. Our research on scientific journal articles (which most of these students would have encountered in their third and fourth year courses in science) found that graphical inscriptions were considerably elaborated with text both in the caption and in the "claims" and data sections of journal articles together mutually constituting the claims and reducing ambiguity in the reading of the inscriptions. Elaboration of this sort does not occur in this report making the reading of the report and interpretation of the inscriptions much more difficult.

Case # 3 (Table 6; Questions 11.a. & 11.b.)

This report addressed the focus questions: “Do the exhaust gases from the cars parking in Lot C directly effect concentration (measure of productivity) of field flowers in front of the lot?” and “Do the exhaust gases form the cars parking in Lot C directly effect height (measure of growth) of field flowers in front of the lot?” To address these questions the students “selected a level area of flowering plants in parking lot C” and measured out a “4x5 m area” which was subdivided “into m^2 sections.” Each quadrant “was examined for growth and productivity of flowering plants.” Productivity was operationalized by counting “each bud/bloom . . . . rather than the stem.” The “height of each flower was measured using a metre stick.” (Details of data presentation and interpretations are found in Figure 10.)

[Insert Figure 10 about here]

Our reading of the report found several issues that were problematic. Both focus questions seek to establish causal relationships between a physical variable (presence of exhaust gases) and the biological variables “concentration” (used as a measure of productivity) and height (as a measure of growth). As written there are conceptual and definitional difficulties with the focus questions being addressed. First, presence of “exhaust gases” is an inference about the effect of the proximity of the parking lot (as stated). Such a connection between “exhaust gases” and proximity to the parking lot would typically be an inference drawn in a “claims section” if proximity to the parking lot was found to be significantly related to growth of the field flowers. Such a claim is also complicated because a busy road (alongside D quadrats) paralleled the parking lot (alongside A quadrats) on the opposite side of the study area. Thus, interpretation of the effects of the independent variable of "exhaust gases" is confounded because it is present on both sides of the research area.

There were further problems in the students' conceptualization of variables. Firstly, as generally used in biological research growth is not operationalized by examining height. More usually, growth means either changes in height over a period of time or the population density of a species of plant. As well, productivity is normally interpreted as a unit output per unit time and not "concentration" (more appropriately referred to as density) as was measured in this study. In addition, the "unit output" would normally refer to the number of plants, not the numbers of "bud/bloom" as were counted. What the report writers actually seek, and what their data allow them to make claim of, are relationships between distance to the parking lot and the biological variables of height and plant density.

In the report data was inscribed in three ways: in a map, two tables, and two line graphs (with strip averages joined). The map depiction (e.g., Figure 10, Data a), isomorphic in its informational value, contained data points corresponding to the actual count of the number of lupines found. This data is then reproduced in a table which is rotated ninety degrees (not shown) having "averages" calculated for the number of lupines in 1-m wide transects (parallel to the parking lot)—although calculating these is of little utility given how the data is utilized in the graph (structured similarly to Figure 10, Data c) and their calculation may have even contributed to the points of average being joined rather than a trend line being drawn. The height data are similarly entered on a table (Figure 10, Data b) with a calculation of average height across the A-D bands. However, this average distorts the data because it is an average of the average heights in each quadrat and therefore quadrats with low number of plants are overemphasized in averages for each band. The drawing of the line joining the averages further distorts any relationship because of the inclusion of the zero-value quadrats (A-1 & C-1) which bias the average value downwards. In analyses such as these it would not be unusual for these zero-height averages to be considered outliers and be excluded from an analysis of average heights.

The participants transformed the data in a categorical fashion using a line graph with the average height in each band connected—a plot of average counts and heights per "quadrant"—not as a trend line in a scatterplot as the data would have allowed. If distance from the parking lot was the independent variable, as the study suggests, then the appropriate Cartesian graph would have included it as a variable. There was also a lack of variable names on the abscissa and brevity in titling/labeling which meant that, as with Case # 2, the representations were not embedded in a thick descriptive context which would help scaffold the reader into interpreting the data in the manner desired by the report writers.

In the report, other than calculating the average height across each of the five plots there were no statistics calculated. Both ANOVA and correlational analyses[9] might have offered better insights into what patterns were apparent in the data, but neither were conducted. In addition, in the calculation of averages in the report no consideration was given to what our ecologists might conclude were data outliers—in both quadrant A and C, there are "zero" values for growth (based on no lupines) which may have warranted exclusion as "outliers" and which influence the interpretation.

Claims are based on data which could have established a relationship between the distance from the parking lot and the height and number of plants. However, the interpretation that "smog" has this relation is not supported by the data given that "smog" is present on both sides of the study site because of the presence of a busy roadway opposite the parking lot. Therefore, the claim (Table 7) that "smog decreases . . . growth..." is unsubstantiated given the data that was collected. Claim 3 acknowledges that the presence of a busy street on the other side of the research site might have had a mediational effect on the productivity (i.e., "total # of buds/blooms") but left undiscussed why this would affect the number of buds/blooms but not the number of lupines (i.e., "growth") present, which was at their highest number next to the roadway. Claim 4 further confuses interpretation by the reader because what seemed to be the

9 In this instance we are unable to offer post-hoc analyses because only summarized data (averages), based on uneven cell size, were given in the report.

dependent variable under study (i.e., "smog") is then implied to be something that the investigators wanted to control (as "control" was discussed in the class and mentioned in reports).

Discussion of the Authentic Investigation Task

Much like the middle school students in the initial phases of previous studies (Scardamalia & Bereiter, 1992; Roth & Bowen, 1993), and despite their previous (for most) science degree(s), these preservice teachers had difficulty constructing productive questions to direct their inquiries. The practices of our preservice teachers were also surprising in the light of the fact that practicing scientists ask "do-able" question, that is, questions that can be answered within the set of contingent constraints under which they have to work. Our present research suggests that their university courses have not assisted them in the development of a sense for distinguishing do-able from not do-able research questions (c.f., Bowen & Roth, 1998b).

The majority of the focus questions investigated in these reports focused on causal and not correlational questions (Table 6). In the context of the activity in which they were engaged, investigating causal questions was generally not feasible being more commonly addressed either in experimental situations or over a considerable period of time—neither of which were possible in this activity. In our past work with Grade 8 students conducting similar (although long-term) field research activities outside we also noticed (unreported data) that their initial investigative questions were often causal. Further, of the 25 focus questions there was some difficulty with operationalization of one or both of the variables in 17 of the questions which would ultimately cause difficulties with claims made in the reports.

These problems are similar to those found in the initial field work projects conducted by Grade 8 students. For instance, the focus questions addressed by the preservice secondary teachers had many similarities to those framed by the Grade 8 students when they first started their outdoor research—many were so conceptually "broad" that it would be difficult to address them in a single outdoor session. These questions addressed issues that were quite ecologically complex, relationships such as "competition," "biodiversity," "growth," and "productivity" all of which have specific meanings in biology that do not equate to "distribution," counts of limited numbers of organisms, or "height" as they were used by the pre-service secondary teachers.[10] This meant that even some of the questions which were stated as a correlation (e.g., Q4.b.) were conceptually actually causal questions because of the concepts involved in the question and how they would need to be operationalized to be addressed (e.g., competition and plant distribution; Q4.b.).

In science it is common practice to record data in tables, for organizational, process, and presentation reasons, and then to transform the data into more abstract representations allowing for the examination of relationships between variables (e.g., Figure 1). Since these studies were to be an examination of measured relations and since the vee-map heuristic prompted for the use of graphs it was not unexpected that tables and then higher order transformations would be frequently used (14 and 15 respectively of 23)—a slightly higher use of graphs than was found for the Lost Field Notebook problem. However, as discussed earlier, there were structural problems with both the graphs and tables resulting in difficulties in interpreting them. This would then compound difficulties in interpretation given that in the Lost Field Notebook and Plant Distribution activities described earlier we documented pre-service teachers having interpretive difficulty even when contextual cues in the form of suitable labels and titles were provided. Also, although only 44% of the respondents drew graphs in the Lost Field Notebook study, those which were drawn were scatterplots—which allowed interpreters to examine patterns of relation between the variables. However, in the reports of the outdoor research project 10 of the graphs which were drawn (to address 8 of the focus questions) were inappropriate for the data and question being addressed. Transforming data into a graph from a structured table is a normal step in the conduct of science and might partly explain why there were discrepancies in graph use in the projects compared to the interpretations of the Lost Field Notebook problem. In

[10] Investigations of causality in ecology often involve experimental designs (as opposed to just observational ones) and occur over considerable periods of time sufficient to address factors such as plant growth, long term growth, competition, etc.

the Lost Field Notebook problem numbers were clearly in pairs which, given that students learn about scatterplots being used for "pairs of data" from Grade 8 onwards, lent themselves to being depicted in a scatterplot. However, in the cases where graphs in the reports were used inappropriately, data was drawn from maps where "pairs of data," such as in the Lost Field Notebook map, were much less obvious. How one structures the data in representing it—how the data tables are structured—appears to influence the graphical inscriptions which result.

Similar to their work in the Lost Field Notebook activity, the pre-service secondary teachers rarely identified outliers and excluded them from analysis which, as shown in Case Study #3, could affect interpretation. Furthermore, lines of best fit were used in only two graphs (in one case seemingly opposite to the pattern, in the other drawn through averages and not raw data) which was a frequency even lower than that reported (26%) used when interpreting the Lost Field Notebook data.

However, just as we argued that tables do not play the role for these students that they do for experienced researchers we conclude that transformed inscriptions also play a different role. In part, this claim arises because of the discontinuity that exists between the text of the claims and the inscriptions. Whereas for experienced researchers the claims and the inscriptions are mutually constitutive, in the majority of these reports claims did not derive from the inscriptions. When examining transcripts of intepretations of the Plant Distribution graph it was clear that scientists used the graphs as a point around which to discuss claims (such as is found in its caption) relating both to their experiences in the field. In the pre-service teacher reports on the Authentic Investigation task the claims only rarely related to the inscribed data and often did not relate to the original question either. This is unlike the coherence found in scientific reports which are written to show questions clearly leading to data which clearly lead to inscriptions which clearly link to the claims which address the original questions. Such a continuity was not present in many of the reports submitted by the pre-service secondary teachers.

If these reports were based on field studies that were expected, by the instructor, to be in-depth, lengthy, and conceptually complex then the number of non-standard approaches and interpretations present in the pre-service teachers' reports might well be understandable. However, the assignment was little different than that done previously with grade eight students who were learning to conduct their own research projects as part of their regular science classes. In spite of the substantially greater education of the pre-service secondary science teachers, they exhibited no greater competency at structuring, conducting, and writing about this type of research activity than the Grade 8 students initially did. Similar difficulties, such as asking causal questions, inappropriately operationalizing variables, inappropriately using graphs, and constructing claims that extended beyond the data initially were not uncommon amongst the Grade 8 students but became almost negligible as they gained more experience in conducting and presenting their own research. The contrast in their competency at engaging in such tasks compared to the student teachers should have considerable implications for teacher education programs.

DISCUSSION

In this study we had participants engage in a number of different tasks which, together, were quite similar to the panoply of practices in which scientists engage as they conduct their everyday work. The tasks progressed from analyzing data (such as students would do in a biology course in which they were learning about the practices of science or scientists would do when reading scientific reports), to interpreting data which had been analyzed and transformed by others (such as students and scientists do when they read research papers written by others) to a project in which participants conducted, analyzed, interpreted and drew conclusions from research of their own design (such as scientists do in their everyday work). In these activities there were both similarities and differences between the practices of working scientists and those of both pre-service teachers and science instructors. However, in general, the teachers and instructors did not often engage in the same practices nor reach the same conclusions of those who were experienced in conducting, summarizing, and analyzing research (including both working researchers and the Grade 8 students from our past work). It would seem that engaging in research projects of one's own design (with all of the components of analyzing and drawing conclusions from this work) is an important component of learning to interpret the work (i.e., writings) of scientists in the ways in which they intend—and this was something which had not been done by the instructors or pre-service teachers. We now discuss some of those similarities and differences and the underlying concepts of significance.

From World to Sign (Text) and Back

According to Latour (1993), nature and its representations can be thought of as lying on an open continuum which, one side, is characterized by increasing levels of locality, particularity, materiality, multiplicity, and continuity and to the right, is characterized by increasing levels of compatibility, standardization, texts, calculation, and relative universality. What scientists (and others doing research) accomplish are transformations of ontologically different representations linked only by consensus on the process and products of transformations between different inscriptions. Our tasks can be mapped onto this continuum to show the different nature of each task (Figure 1). In the Lost Field Notebook, the task requires participants to transform the data into an inscription to the right, and then to reconstruct a nature setting in which the data might have been collected. In the Distribution Graph, the task was to read the graph as a story that had a referent in the world not only about the distribution of plants, but about the adaptation of plants to particular environments. Finally, in the Authentic Inquiry tasks, participants were asked to go full circle—rather than reconstructing environments from texts (graph/caption), they actually know the setting about which they were to make some general statement. Thus, despite the fact that the task involved more steps, it might have been easier given that they were making a statement about an ecozone with which they had personal experience.

Although the (preservice) elementary teachers did not translate their data in the Lost Field Notebook task, and therefore had little to say about the overall relations between the two variables, they did reconstruct possible scenarios that could have led to the particular data they had in front of them. On the other hand, the Distribution Graph led one group of preservice elementary science teachers and one instructor to make explicit links to their personal experiences related to changing fauna with changing climes and elevation; most activity remained referentially isolated in the context set by the sign structures (words, data, lines).

Scientists had a singular set of practices for dealing with the Lost Field Notebook: plotted the data, proposed regression analysis to test goodness of fit, discussed an outlying data point, and suggested the collection of additional data to increase the power of the statistical analysis. Our past research with pre-service secondary teachers reported that they infrequently used graphs to address the Lost Field Notebook problem and in this study we found that "priming" them about the importance of using graphs to make correlative arguments resulted in an increase in graphs being used when addressing the Lost Field Notebook problem. However, even with this priming it was still only a minority of students that used scatterplots. We turned to the Authentic Investigation task to obtain further insight into why the priming was ineffective. From these reports we realized that the difficulties lay not in knowing if a graph should be used, but rather, was embedded in not knowing how to structure data and choose appropriate inscriptions to address problems.

Epistemology

Instructors and pre-service teachers acted as if a relationship had to be unambiguous, all data points consistently "in line" with each other. Here, the belief in a mathematical nature of the universe is inherent in the explanations—there did not seem to be another way. Thus, variation in one of the two variables with constant second variable, or a comparison of a negative relationship between two data pairs, was sufficient to reject a positive relationship between the two variables.

Where might this default practice come from? Given students' experience with science from science textbooks and lectures, and their mathematics experiences—where they likely would have been plotting functions—they would have seen predominantly, if not exclusively, line graphs and "data points" that fell, in an ideal way, on the line. In these sources there is a didactic use of clean line graphs; and in the few cases that "data" were plotted, these fell exactly on the best-fit line on the graph[11] (Roth, McGinn, & Bowen, 1997).

It has been noted that scientists believe in the isomorphism of nature and mathematics (Lynch, 1991); in many cases, and for a historically long period, scientists believed that the world is inherently mathematical such that mathematical structures not only describe but in fact are responsible for the patterns in the world. Our research shows that not only scientists appear to operate as if nature was inherently mathematical. Furthermore, the very practices of using graphical representations and the mathematics activities in which functions are plotted may be at the origin of such default, commonsense and mundane assumptions about the world.

Significance for Educating Science Teachers

Overall, although the preservice secondary teachers had undergraduate and even graduate degrees in science, they did not default to practices that scientists use routinely in their everyday work. This has implications for undergraduate science education and science teacher education. As we found in the previous study where we examined the responses of teachers to the Lost Field Notebook problem, the results of this study suggest that most preservice teachers do not seem to be ready to teach scientific practices of interpretation in the way advocated by curriculum reform. Of even more concern was their difficulty in conducting and summarizing an open-ended research project of their own. In scientific communities participants ask do-able questions and use graphing on a day-to-day basis as default approaches to participating in the domain (Fujimura, 1987). As many of our participants had science degrees, we might expect them to default to these practices. This was not the case, and is even less likely to occur when there is less scientific training as part of a teacher education program—as occurs in many U.S. universities and colleges. If teachers have difficulty asking "do-able" questions themselves, how

[11] Such a description also characterizes relationships between variables as they appear in newspapers and news magazines.

are they to scaffold students towards asking them so that they can effectively engage in activities which have a high degree of similarity to scientific inquiry? We suggest that not asking such questions oneself in the context of "authentic" field investigations indicates that there will not be the requisite recognition of appropriate or inappropriate questions asked by students that would be necessary to help students develop such skills. Simply telling preservice teachers which questions are appropriate or inappropriate outside of the context of their engagement in lab investigations will not increase their competence in helping students ask appropriate questions. That preservice teachers do not engage in these practices is not a critique of them individually, but rather a commentary on the efficacy of the experiences they have engaged in their undergraduate studies.

Our research has considerable implications for the preparation of science teachers. At the present, our preservice teachers did not seem to be ready to competently teach inquiry and data analysis in the way suggested by recent reform documents (AAAS, 1993; NCTM, 1989). Representing is a central part of science (Latour, 1987) and being able to scaffold students into the appropriate use of graphs and tables in the context of addressing questions which are do-able is something that teachers need to be able to do to address the curriculum reform documents. Thus, despite the considerable amount of preparatory course work that these preservice teachers had taken in science, they were insufficiently prepared to teach in the way we would like them to. As with the telling of student teachers what "appropriate" questions are for investigation, we also do not think that simply telling preservice teachers which graphs or other tools of interpretation are appropriate will increase their competence in helping students learn canonical methods of data analysis and interpretation. We have argued elsewhere (Roth & Bowen, in press; Roth & McGinn, 1998) for changes in teaching science that would focus on graphing as social and cultural practices in which student teachers should become more engaged as part of their undergraduate science work. This should address what is clear from our work with preservice teachers and in undergraduate science classrooms—that they have little practical experience engaging in the mathematical practices of science. Structural change is needed in the undergraduate experiences of preservice teachers if they are to fulfill the goals of the reform documents and have their own students engage in the daily scientific practices of asking do-able questions and making claims based on appropriate use of various inscriptions and representations. In our social practice framework, preservice teachers need to have more experience in using graphing to help construct rhetorical claims around investigations they have designed. This would seem to be the most effective way for them to become enculturated into the practices of science which they can then use as a foundation to enculturate their own students. However, as members of a community involved in preparing teachers to go into schools and teach children, we therefore have to question (a) whether the objectives in our reform documents are realistic given the current teaching practices in colleges and universities and (b) what kind of science experiences would prepare preservice teachers with undergraduate degrees in science in a better way for meeting the challenges posed by the visions of the reform documents.

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CAPTIONS

Figure 1. Relations of inscriptions between world and sign

Figure 2. (a) Lost Field Notebook task, (b) Scatterplot of LFN data

Figure 3. Plant Distributions graph and caption

Figure 4. Non-linear scatterplot drawn by "Steve" for LFN task. "Steve" had axis reversed compared to all others who used a scatterplot to address the task.

Figure 5. Solution to LFN task by (pre-service) secondary teacher.

Figure 6. Solution to LFN task by (pre-service) secondary teacher who dealt with the data in two sets: (a) scatterplot of four locales for which a correlative relationship was claimed, (b) scatterplot of four locales for which a claim was made of no relationship.

Figure 7. Semiotic model of reading graphs. The upper left hand side represents the process of perceptually individuating some element that has the potential of becoming a sign object. On the lower right hand side, signs are read as being about natural objects. Conventional constraints r on sign use, and contextual constituents c of individual sign elements mediate the reading of the graph.

Figure 8. Scans of data & transformations from Case #1's report.

Figure 9. Scans of data & transformations from Case #2's report.

Figure 10. Scans of data & transformations from Case #3's report.

Table 1. Participants and task distribution.

Table 2. Strategies used and comparisons made by instructors.

Table 3. Distribution of data transformations and types of claims by preservice secondary teachers.

Table 4. Numerical strategies and comparisons made by preservice elementary teachers.

Table 5. Comparative reasoning patterns and strategies deployed with individual data points.

Table 6. Summarization of the research reports for field investigation task complete by preservice secondary science teachers.

Table 7. Claims made in the reports of the three case studies.

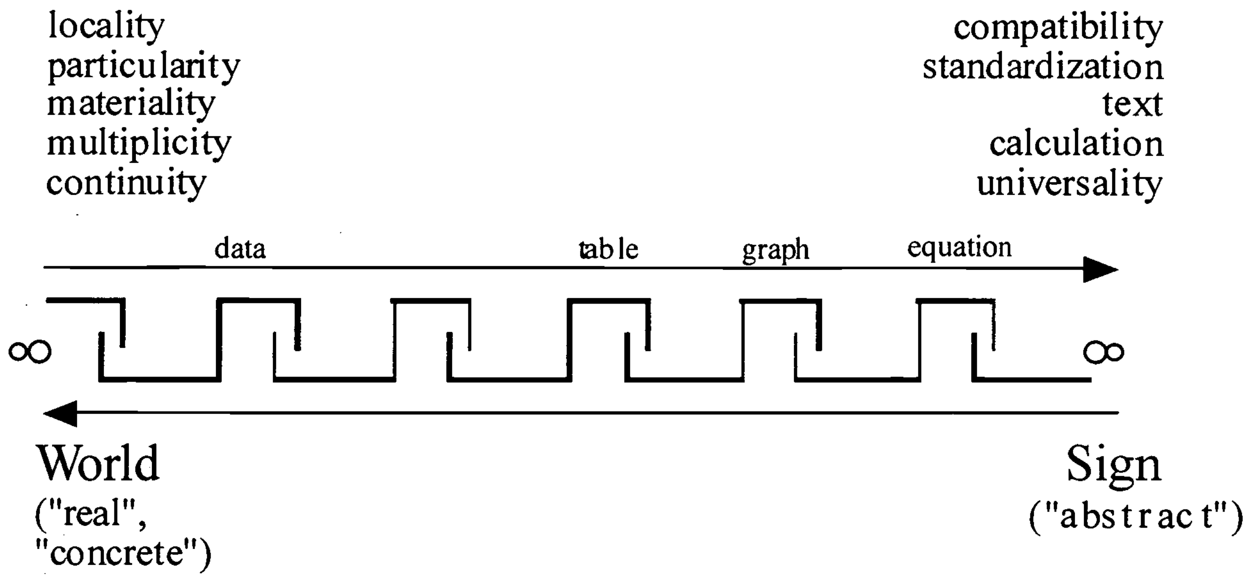


Figure 1. Relations of inscriptions between world and sign

Figure 2

a.

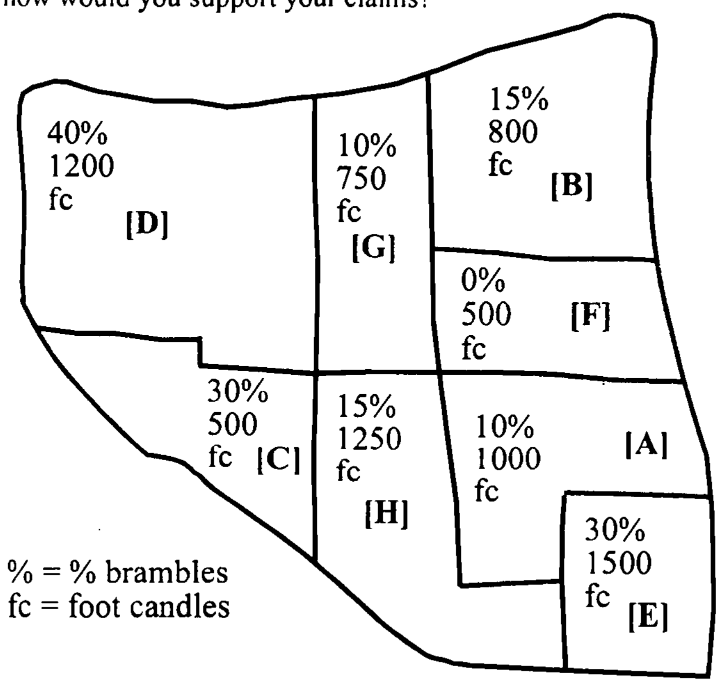
The lost field notebook

Elizabeth is a grade 8 student who is doing research on an ecozone. She wanted to find out whether there is a relationship between the density of brambles, a plant with a long narrow stem, and the amount of light these plants receive in different areas of her ecozone.

She subdivided her ecozone into smaller areas. In each area she measured the approximate coverage of the area (in %) by the brambles. For each area she also found the average amount of light, measured in foot candles (fc). She recorded her data in her field notebook in the form of a the map reproduced below.

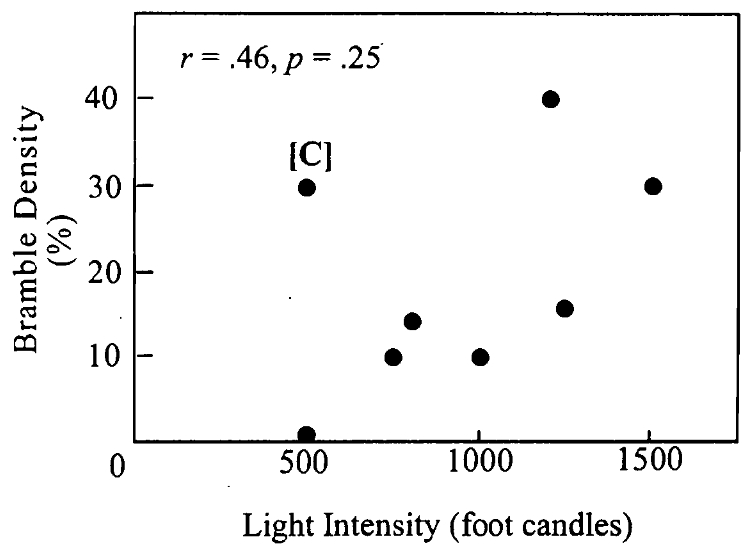
Elizabeth lost her field notebook, and you found it. You wanted to know the patterns she had found, but besides the map there was no additional information. Based on the information provided,

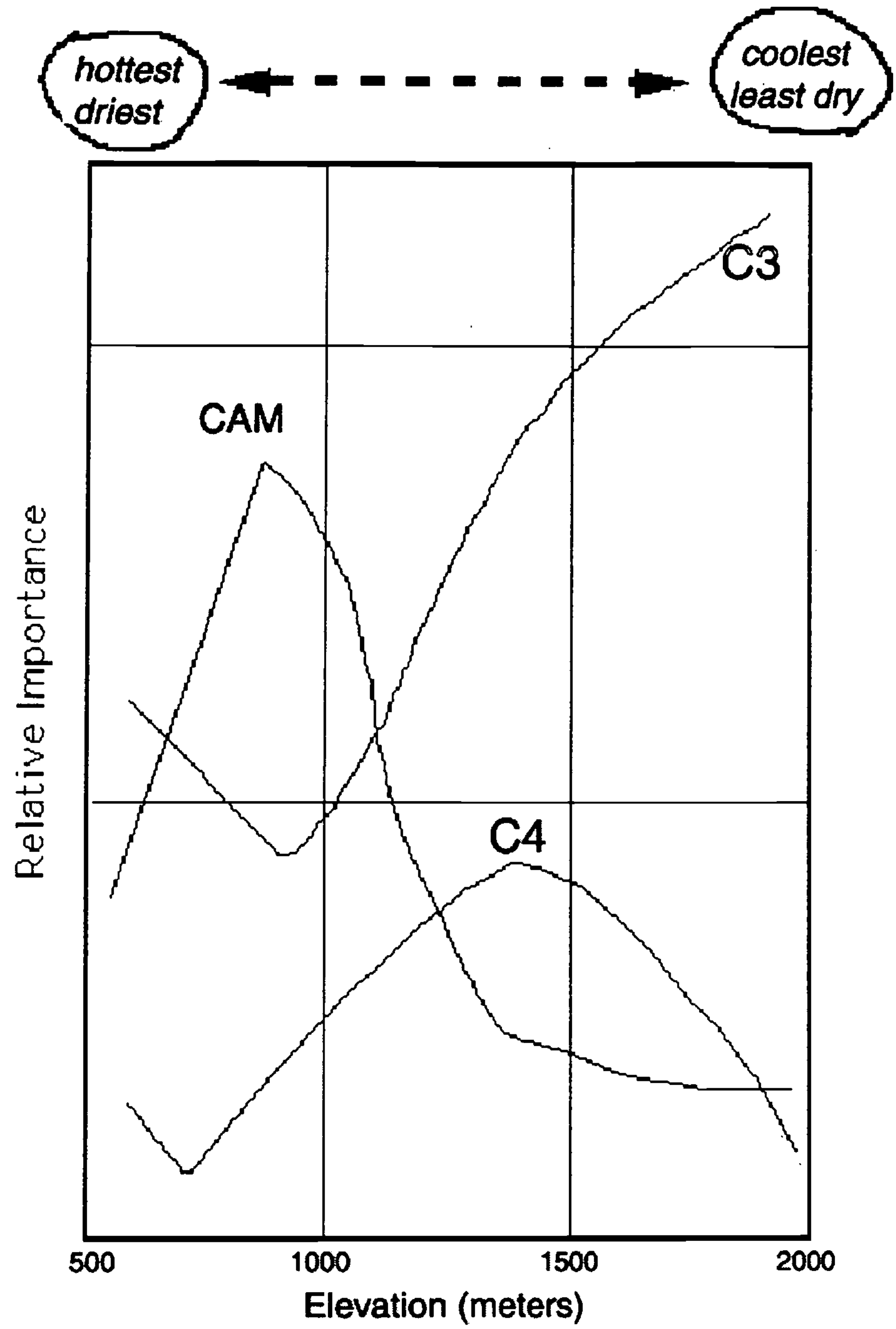
1. what patterns, if any, do you see?
2. what claims would you make?
3. how would you support your claims?



% = % brambles
fc = foot candles

b.





Distribution of C3, C4, and CAM (succulent 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, C4 plants are maximally important under immediate temperature and moisture conditions, and C3 plants predominate at the cooler, least dry end of the gradient. (Modified data from Eickmeier, 1978)

Figure 3. Plant Distributions graph and caption

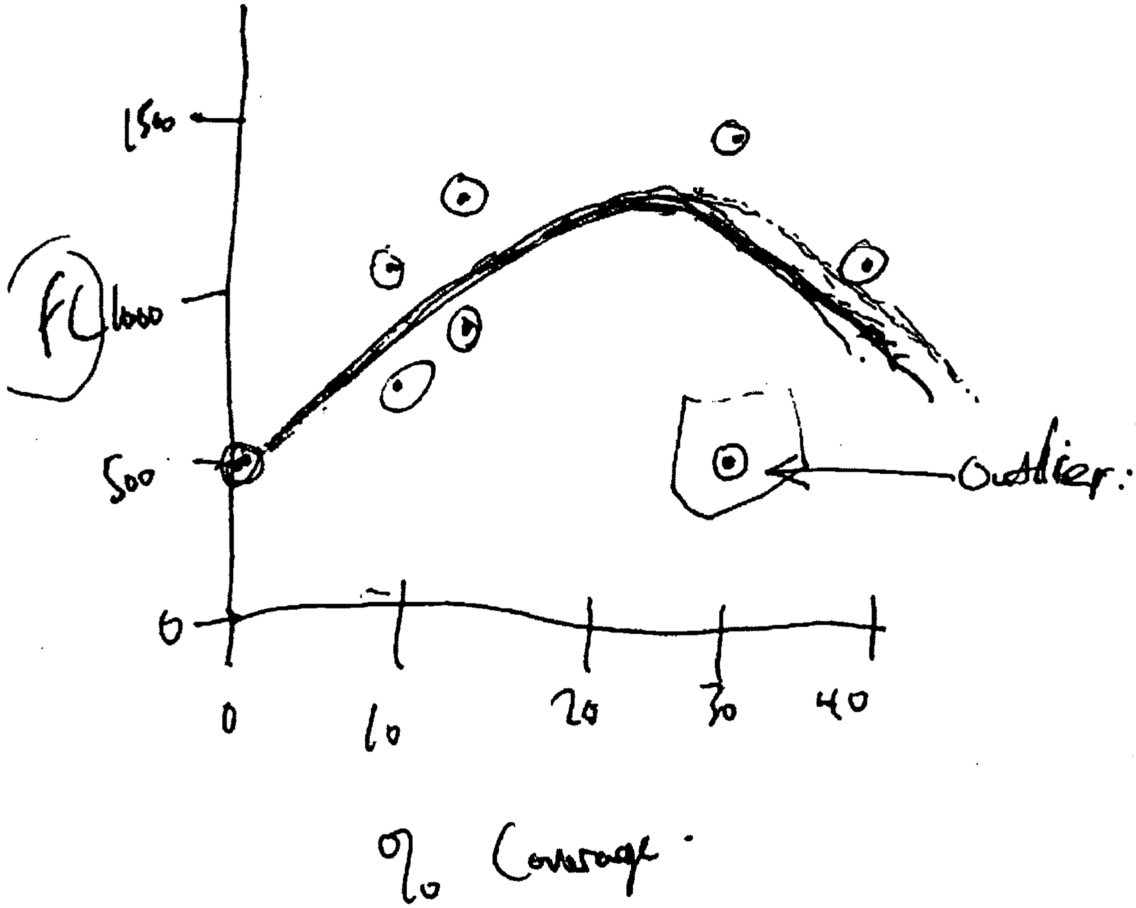
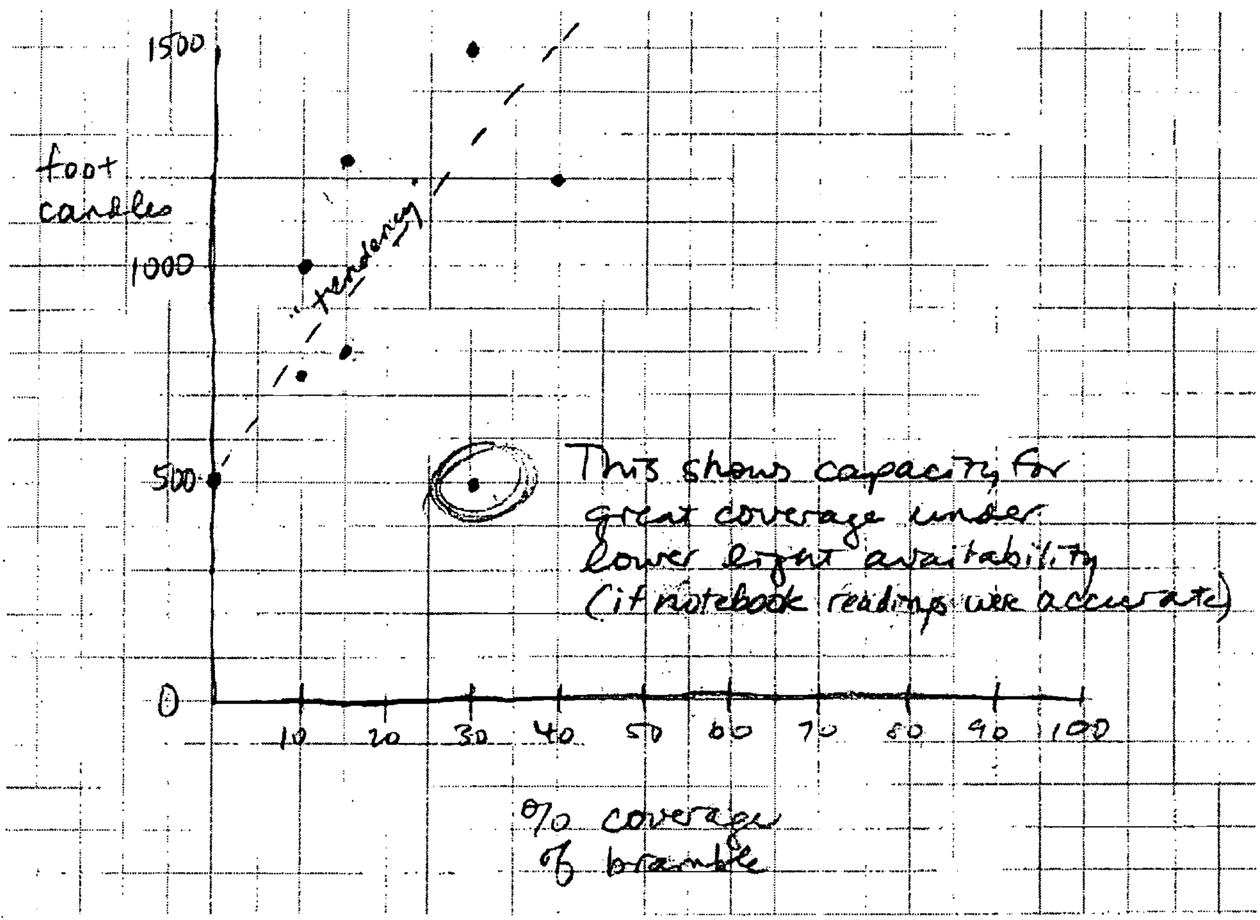


Figure 4. Non-linear scatterplot drawn by "Steve" for LFN task. "Steve" had axis reversed compared to all others who used a scatterplot to address the task.



The Lost Field Notebook

1. Patterns seen:
   —"Tendency" for increase in foot candles => increase in % coverage but not absolutely shown by figure above.
   —One major inconsistency: 30% coverage @ 500 f.c. but also 30% coverage @ 1500 f.c.
   —Outer areas have greater % coverage, generally
2. Claims:
   —Suggest different soil temperature, terrain types
   —Suggest different water supply
   —Shows plant is able to grow in lower lighting conditions
3. Support:
   —From graph of data
   —Must be factors other than light

Figure 5. Solution to LFN task by (pre-service) secondary teacher.

a. **b.**

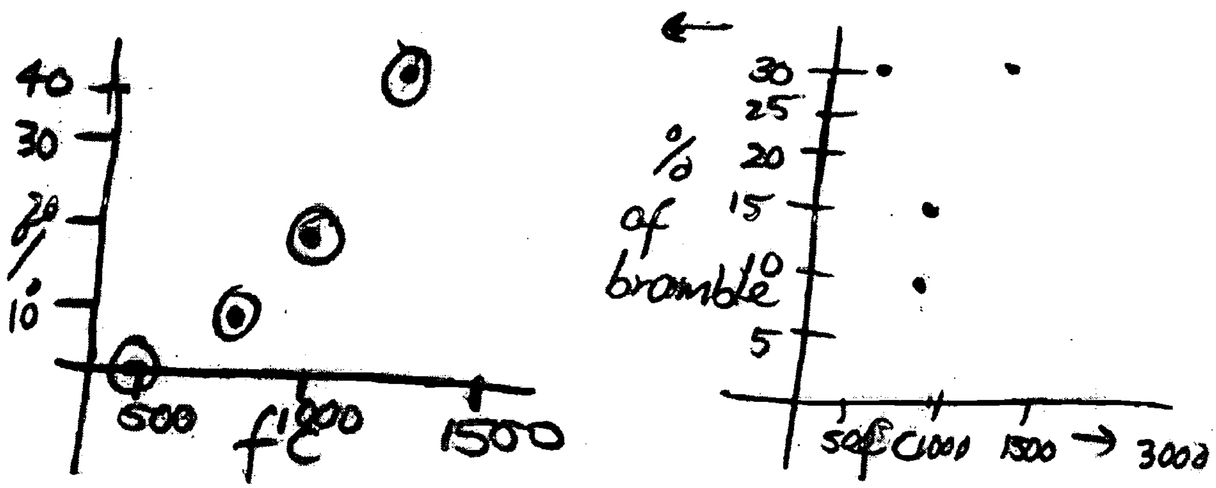


Figure 6. Solution to LFN task by (pre-service) secondary teacher who dealt with the data in two sets: (a) scatterplot of four locales for which a correlative relationship was claimed, (b) scatterplot of four locales for which a claim was made of no relationship.

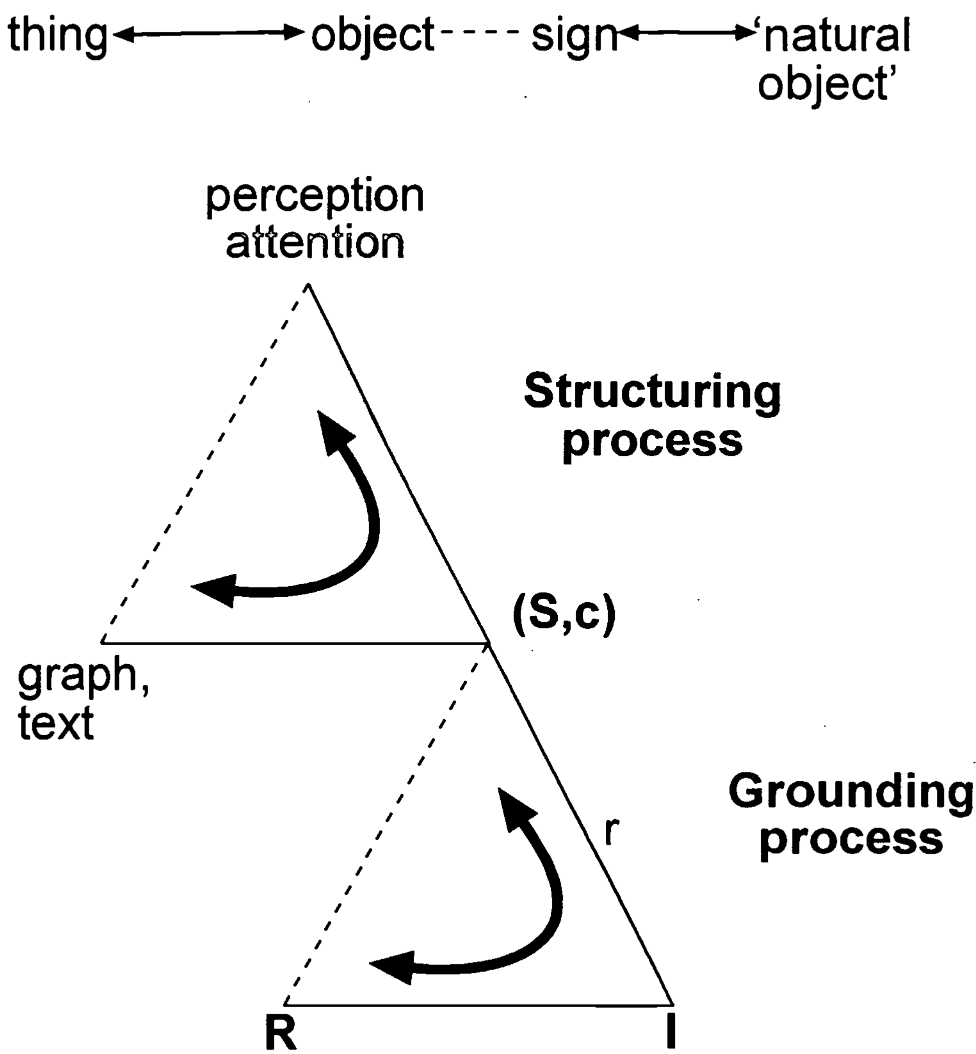


Figure 7. Semiotic model of reading graphs. The upper left hand side represents the process of perceptually individuating some element that has the potential of becoming a sign object. On the lower right hand side, signs are read as being about natural objects. Conventional constraints r on sign use, and contextual constituents c of individual sign elements mediate the reading of the graph.

Data:

TABLE 1: Soil moisture, Maximum Horse-tail height (cm) and Horsetail [illegible]

[illegible]	[illegible]	[illegible]	[illegible]
1	7.34	NA	0
2	7.89	NA	0
3	7.16	NA	0
4	7.26	NA	0
5	7.20	NA	0
6	7.90	NA	0
7	8.26	NA	0
8	8.09	NA	0
9	6.96	11	4
10	7.80	13	9
11	8.36	11	14
12	8.10	13	17
13	7.70	15	11
14	7.50	18	27
15	7.40	20	55
16	6.94	19	57
17	5.84	30	3
18	7.10	21	32
19	6.84	21	40
20	6.84	21	49

Transformed Data:

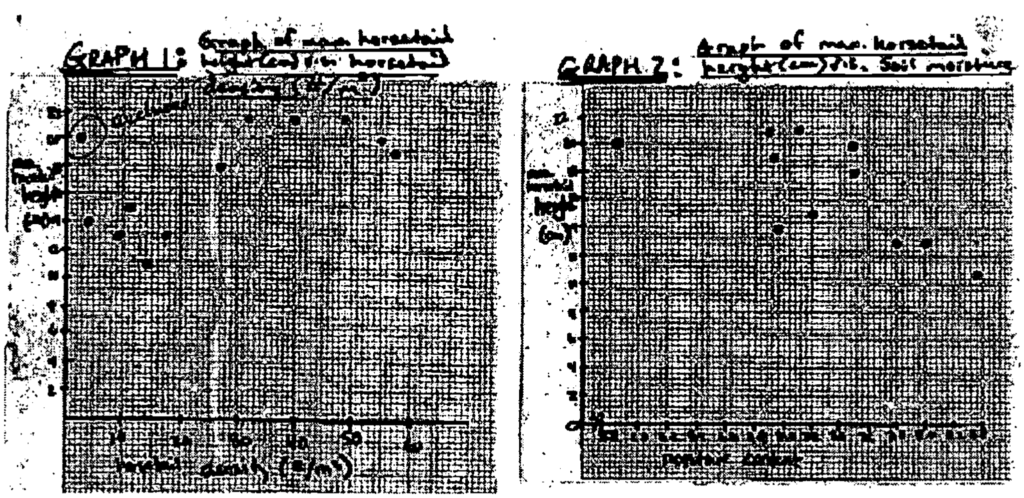


Figure 8. Scans of data & transformations from Case #1's report.

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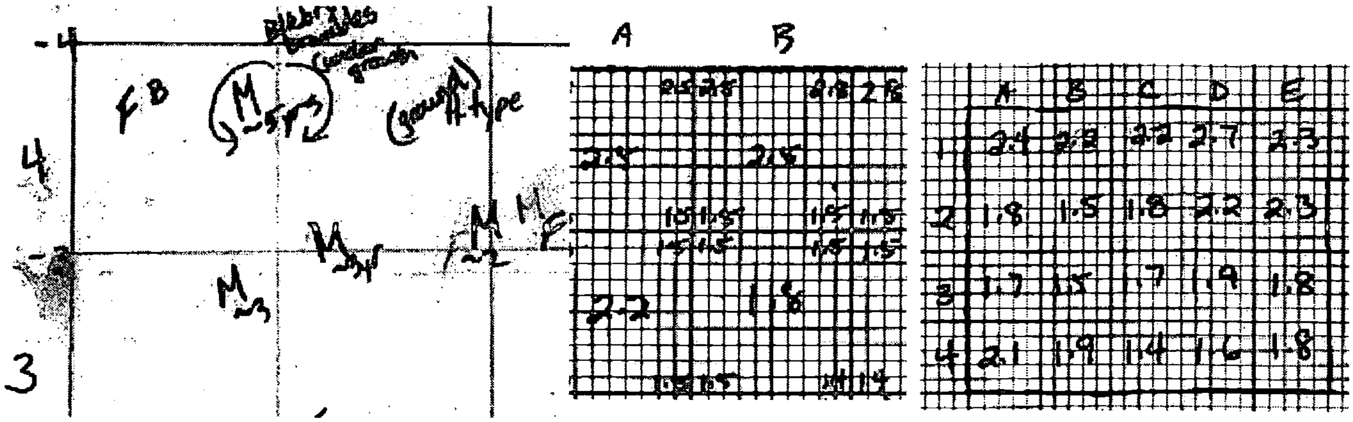
Data:



Transformed Data:

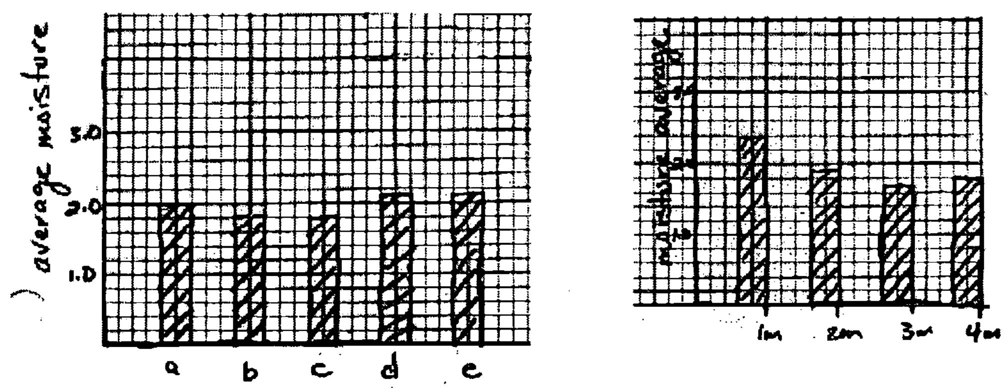
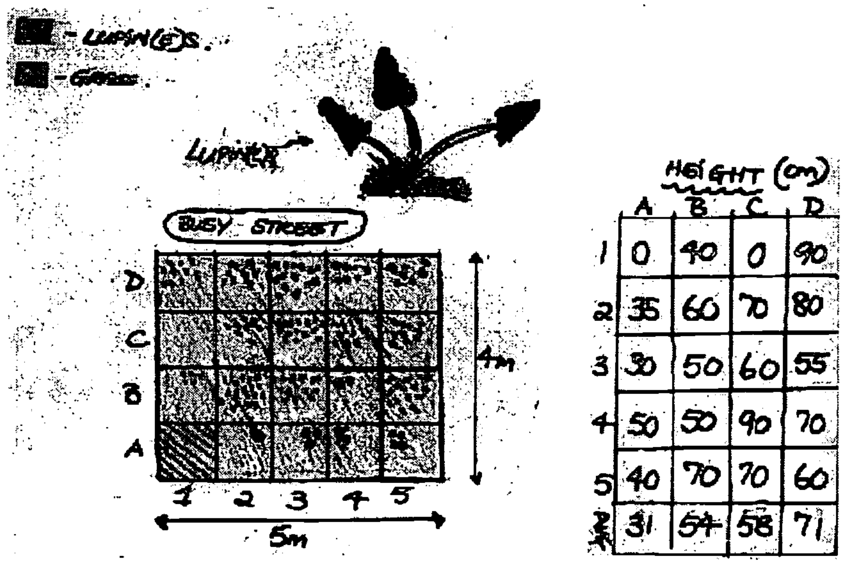


Figure 9. Scans of data & transformations from Case #2's report.

Data:



Transformed Data:

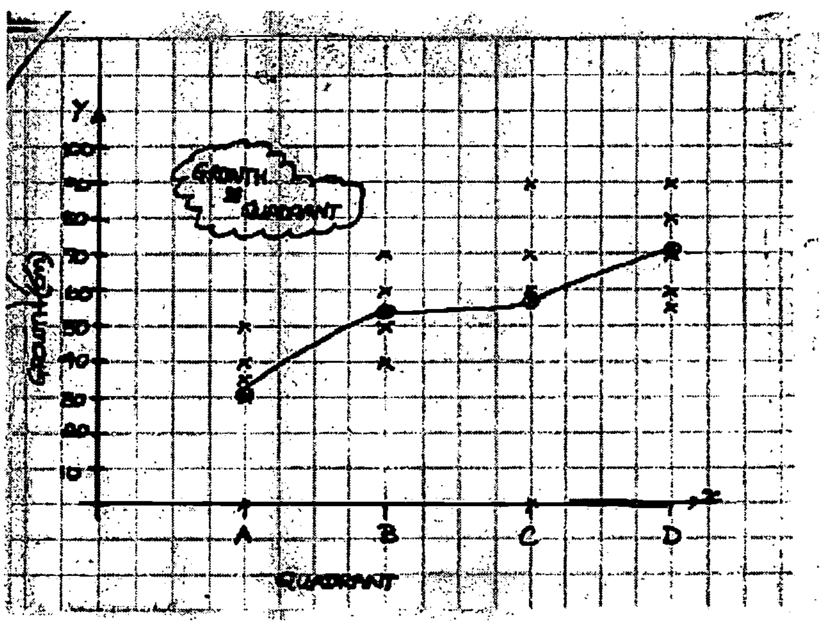


Figure 10. Scans of data & transformations from Case #3's report.

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Table 1

Participants and task distribution

Population	Task		
	Lost Field Notebook	Plant Distribution Graph	Authentic Investigation
Research Scientists (*N*=15)	Think aloud (10)	Think aloud (10)	
Science teachers with B.Sc. (*N*=4)	Think aloud	Think aloud	
Preservice Elem. Science Teachers (*N*=10)	Pairwise Protocol (5 pairs)	Pairwise Protocol (5 pairs)	
Preservice Sec. Science Teachers (*N*=25)	Written (individual)		Written (11 pairs, 1 triad)

Table 2

Strategies used and comparisons made by instructors

	Strategies			Total
	Within	Between	Cross	
Ike	4	3		7
Ira	1		1	2
Ian	1		2	3
Ina	3	1		4
Total	8	4	3	16

Comparisons	
CD:	2
CE:	1
CF:	6
DE:	1
DH:	2
DEC:	1
DEH:	1
HAD:	2

Table 3

Distribution of data transformations and type of claims by preservice secondary teachers ($N = 27$)

Representation	Relationship	
	Yes	No
Plot + best fit (outlier)	6	1
Plot only	0	4
	(.5)	(.5)
Table	0	5
Verbal	0	8
Other (cross section, ratio)	0	2

Table 4

Numerical strategies and comparisons made by preservice elementary teachers

	Strategies				**Total**
Group	Within	Between	Cross	Qual (Within)	
A	0	6	0	2	8
B	1	2	1	3	7
C	0	1	0	2	3
D	0	0	0	5	5
E	1	0	1	1	3
Total	2	9	2	13	26

Comparisons	
BH:	0 (1)
CD:	0 (2)
CE:	1 (2)
CF:	5 (1)
CH:	0 (1)
DE:	2 (3)
DG:	2 (1)
DH:	3 (1)
GH:	0 (1)

Table 5

Comparative reasoning patterns and strategies deployed with individual data points

Reasoning	Data Points Deployed	Strategy B	Strategy W (qual)	Strategy X	Total
high:high, low:low	D:G, D:E	3	0	0	3
			(4)		(4)
different %:	D:H, C:F, D:E:F, H:A:D	9	13	2	24
same/similar fc			(4)		(4)
same/similar %:	C:E, B:H, C:D, G:H, D:C:E	3	3	2	8
different fc			(7)		(7)
increase: decrease	D:E, C:H	0	2	1	3
decrease:increase			(0)		(0)
Total		15	18	5	38
			(15)		(15)

Table 6

Representation of the research conducted by preservice secondary science teachers with science degrees

<table>
<tr><th>Question</th><th>Design (operationalization)</th><th>Data Representation</th><th>Transformation</th><th>Claim</th></tr>
<tr><td>1.a. REL
[host preference]
[species]</td><td>[#bugs] || [species]</td><td>MAP[plants]
TAB([site#][species],
[frequency])</td><td>SUM[#bugs], AVG[#bugs]
WHISKER([AVG],[species])</td><td>REL([preference], [species])</td></tr>
<tr><td>1.b. CORR
[light intensity]
[distribution]</td><td>[light intensity] || [location]</td><td>TAB([row#][column#],
[light intensity])</td><td>MAP([intensity][isolines],
[location])</td><td>+CORR([light intensity],
[distribution])</td></tr>
<tr><td>2.a. CORR
[height] [density]</td><td>[height] || [#species/m^2]</td><td>MAP([rel. coverage],
[location])
TAB([x-loc] [y-loc],
[moisture] [height]
[density])</td><td>SCATTER([height],[density])</td><td>+CORR([density], [height])</td></tr>
<tr><td>2.a. CORR
[height] [moisture]</td><td>[height] | [moisture]</td><td>"</td><td>AVG[moisture]
SCATTER([height],[moisture])</td><td>-CORR([moisture], [height])</td></tr>
<tr><td>3.a. CORR
[moisture] [slope]</td><td>[moisture] || [x-loc] [y-loc]</td><td>MAP([moisture][plant loc]
[plant height], [x-loc][y-loc])
TRANS([species][location])
TAB([x-loc][y-loc],
[moisture])</td><td>BAR([density],[x-loc])</td><td>♣ noCORR([slope], [moisture])
♣♦ CAUS([competition], [growth]
[density] [distribution])</td></tr>
<tr><td>3.b. CAUS
[moisture]-->
[distribution]
[moisture]--
>[height]</td><td>♥ [moisture] || [# horsetails,
x-loc]
♥ [moisture] || [height]</td><td>"</td><td>SCATTER([height],[moisture])</td><td>♦ REL([# horsetails]
[disturbance])
♦ -CORR([[disturbance]/
[moisture]], [height])</td></tr>
</table>

4.a. CORR [pH] [distribution]		[pH] | [rel. coverage]	MAP([rel. coverage], [location]) TAB([species], [% coverage]) TAB([location], [pH])		<none>		noCORR([pH] [distribution])
4.b. CORR [competition] [distribution]		[interface] | [rel. coverage]	"		<none>	♣ ♣	competition([species1] [species2]) competition([species2] [species3])
5.a. CAUS [pH]-->[vegetation]	♥	[pH] || [species]	MAP[plants] TAB([trial#][species],[pH])		AVG[pH] BAR([AVG],[species])		noREL([pH], [species])
5.b. CAUS [moisture]-- >[vegetation]	♥	[moisture] || [species]	TAB([trial#][species], [moisture])		AVG[moisture] BAR([AVG],[species])	♣	CAUS([moisture],[species])
6.a. CAUS [moisture]-- >[growth]	♥	[moisture] || [species]	MAP([rel. coverage][moisture], [location])		<none>	♣ ♣♦ ♣♦	+CORR([species1],[moisture]) +CORR([species1],[light]) +CORR([species1],[gradient])
6.b. CAUS [overstory][mid- story]--> [growth]	♥	[species]	"		<none>	♣	<none>
7.a. CORR [moisture] [slope]		[moisture] | [x-loc][y-loc]	TAB([x-loc] [y-loc], [moisture])	♠ ♠•	AVG[moisture] BAR([moisture],[x-loc]) BAR([moisture],[y-loc])	♦	-CORR([x-loc], [moisture])
7.b. CORR [distribution] [moisture]		[plants] | [moisture]	MAP([plants], [x-loc][y- loc])		<none>	♣	noCORR ([species1], [moisture])

8. CORR [growth] [pH] [moisture]		[rel. coverage] || [pH] , [moisture]	MAP[relative coverage] TAB([rel. cover], [pH][moisture])	♠ ♠	lineG[pH],[rel. coverage] lineG[moisture],[rel. coverage]	♣ ♣	noCORR[pH], [rel. coverage] noCORR[moisture], [rel. coverage]
9.a. CAUS [slope]-->[moisture]	♥	[gradient][x-loc] || [moisture]	<none>	• ♠ •	AVG[moisture] SCATTER([x-loc],[AVG]) SCATTER([gradient], [Δmoisture]) BAR([x-loc],[% gradient])	♦	+CORR([gradient] [moisture]) REL([gradient], [x-loc])
9.b. CAUS [slope]-->[coverage]	♥	[x-loc] || [% species1]	MAP([rel. coverage], [location])	♠•	BAR([x-loc],[% species1])	♣	+CORR([gradient], [%cover])
10.a. CAUS [pH]-->[vegetation type]	♥	[pH] | [#species1][#species2]	MAP([pH] [species1] [species2], [x-loc][y-loc])	♠	BAR([pH][#species1] [#species2],[location])	♣	Inconclusive
10.b.CAUS [pH]-->[vegetation quantity]		"	"		"	♣	Inconclusive REL([pH], [location])
11.a. CAUS [pollution]—> [productivity]	♥	[distance to parking lot] || [#buds/blooms species1]	MAP([species1],[x-loc][y-loc]) TAB([row#][column#], [#buds/blooms])	♠	AVG[#buds/blooms] LINEG([AVG],[x-loc])	♣	-CORR([smog]|[x-loc], [productivity])
11.b. CAUS [pollution]—>[growth]	♥	[distance to parking lot] || [height]	TAB([row#][column#], [height])	♠	AVG[height] LINEG([AVG],[x-loc])	♣	CORR([x-loc][growth])

12.a. CAUS [feature]—>[biodiversity]	♥	[aspect] || [rel. frequency species]	MAP([plants][pH])	♠	BAR([rel. frequency], [aspect])	♣♦ ♣♦ ♣♦ ♣♦ ♣♦	REL([aspect], [species]) -CORR([species1], [light]) +CORR([species1], [moisture]) +CORR([species2], [heat/light]) -CORR([species2], [moisture])
12.b. CAUS [substrate]—>[biodiversity]	♥	[location] || [pH] [rel. frequency species]	"		<none>	♣	<none>

Key: CORR - correlational statement/claim made (i.e., one variables measure covarys with another measure)
REL - relational claim made (i.e., with categorical variables)
CAUS - causal statement made (i.e., one variable causes another to change)
TAB - data represented in a table
MAP - data represented in a map/drawing
TRANS - landscape viewed in a side profile
BAR([y][x]) - Bar graph used
SCATTER([y][x]) - Scatterplot graph used
LINEG([y][x]) - Line graph used
WHISKER([AVG][species]) - categorical graph plotting averages w/ range in each category used
AVG[variable] - average given for a variable
single underline - conceptual problem in operationalization of variable
double underline - problem in implementation of operationalization of variable (e.g., replication, sampling)
♥ - problem of relation of variable1 to variable2
• - transformation not related to original question
♠ - inappropriately used graph (e.g., bar instead of scatterplot)
♦ - claim not related to original question
♣ - claim is not conceptually related to the data which was collected and presented

Table 7

Claims made in the reports of the three case studies

	Claims in Reports
Case Study 1	1. We found that the area with the highest horsetail density had the horsetails with the tallest height. This could be that the areas with the highest density had the most favorable conditions such as nutrients, shade, and light, which allowed them to grow taller. 2. We found that the areas with the least moisture content had the horsetails with the tallest height. This could be that the taller horsetails have absorbed more water (nutrients) thus reducing the moisture content of the soil. 3. Additional questions that might require further investigation might include how competition with other plant species affects the height and density of horsetails; how soil type affects soil moisture; and why the density of horsetails decreased with proximity to the road.
Case Study 2	1. Moisture at the top of the slope on a sunny day is greater than in the middle or bottom. This is probably due to moisture (e.g., rainfall) hitting the soil at the top more often than elsewhere because of how various plants on the slope prevent moisture from accessing the soil, i.e., there are fewer plants at the top of the slope. Gradually, rainwater at the top would run down the hill because of gravity. 2. Further tests could help determine the effects of plant type versus position on slope. We also might learn more by taking moisture readings in the soil during or after various degrees of rainfall. Presumably, different plant types utilize different amounts of moisture so we could test soil moisture around various types. 3. Pattern of fern placement on the slope is not related to moisture content of the soil. 4. Further tests could indicate whether fern placement pattern is due to competition from other plants, symbiotic relations with other plants, availability of sun versus shade, pH of soil, wind resulting in fertilization and distribution of spores, animal movement resulting in distribution of spores, animal and human traffic effecting survival of plants.
Case Study 3	1. It is possible that smog decreases both productivity and growth of lupines. 2. Growth shows a more consistent correlation with distance from the parking lot (used as a measure of concentration) compared with the productivity. 3. The fact that a street exists on the opposite side of the parking lot indicates why a decrease in productivity occurs in quadrants after B. 4. One parameter that was not controlled in this investigation was the influence of smog.

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