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Improving the Graph Interpretation Competencies of Preservice Secondary Science Teachers Through Long-Term Independent Inquiry Project Work

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Abstract

Understanding graphs is a necessary component of understanding science communication. Previous work indicated that pre-service science teachers have difficulty with this sort of data interpretation (Bowen, Bartley & Melville, 2025; Bowen et al., 2016). It is suggested that experience in conducting independent field work may be necessary to increase the competency of pre-service science teachers in graphing practices. A previous study (Bowen & Roth, 2005) suggested that an improvement in competency was not gained from engaging in a short-term inquiry project, much as short-term engagements have not improved Nature of Science understandings (Edgerly et al., 2023; Akerson et al., 2006, 2017). Evidence from this study suggests participation in an extended inquiry project did improve several aspects of discourse over and about graphs. Three positive outcomes from engaging in a long-term inquiry project are identified: (1) There was an improved canonical use of inscriptions as demonstrated by a higher use of abstract transformations, (2) There was an increase in the use of external referents, (3) There was an increase in the use of personal experiences to make sense of the components of the data problem and to interpret the relationships. Implications of these findings for preparing science teachers are discussed.

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Introduction

Graphs are considered central in the formation and communication of scientific findings (Gardner, Angra & Harsh, 2024; Latour, 1987). They play the role of not only representing data, but also of constraining it and summarizing it in ways that "lose" contextual information contained within the raw data, as transformation from "real world" to data table to graphical representation occurs (with "ontological gaps" occurring between each; Bowen & Roth, 2005). Competent graph users interpret graphs with an understanding of the limitations of the representing role that they play and the other "real world" factors that may be influencing the depicted relationships. However, because of the contextual nature of graphs, even scientists may not be fully competent when it comes to interpreting graphs outside of their domain, or when they do not know about data collection details such as instrumentation, natural phenomenon, and data transformations (Roth, 2003). Findings reported in that study of scientists are consistent with a study of eighth-grade students engaged in a ten-month empirical investigation of natural environments that reported a relationship between their data analytic competencies and their contextual knowledge of the environment (Roth, 1996). Similarly, university science graduates in a science teacher education program experienced difficulties interpreting data in a word problem, which was attributed to their lack of familiarity with both data interpretation and with the natural biological settings from which the data originated (Roth, McGinn, & Bowen, 1998).

Much like research suggesting that single-course efforts to improve Nature of Science understandings were unsuccessful (Akerson et al., 2006; Edgerly et al., 2023), an earlier pilot study suggested that engaging Preservice Secondary Science Teachers (PSSTs) in short-term independent inquiry projects as part of their science methods course contributed to the development of their written rhetorical skills (i.e., such as in their final written reports), but did not reflect their competency in other domains such as graph and data interpretation (Bowen & Bencze, 2009). In contrast, a recent study (Bowen & Hembree, 2025) suggests that increasing competence in research practices involving use of graphs arose from experiences participating with longer term fieldwork research.

This article examines data interpretation outcomes which emerged from efforts to provide PSSTs in a secondary science biology methods course with an inquiry investigation experience to help them better appropriate, and therefore enact, canonical scientific practices. Based on outcomes from our earlier pilot study (and previous classroom experiences that also reflected those outcomes), we engaged PSSTs (Biology) in their own extended inquiry projects and then provided them with opportunities to discuss both their own graphs and those of others to better understand their competencies at interpreting data.

Background

Preservice teachers and science teachers are expected to understand both the knowledge and the practices of science (see Morrell et al., 2020a, 2020b) because they are expected to develop their own students' "…skills and dispositions to use scientific and engineering practices to further their learning and to solve problems" (Morrell et al., 2019, p. 100). Many researchers have argued that science teachers (and therefore preservice science teachers) need to have more comprehensive backgrounds in science practices and skills (Bowen et al., 2016;

Crawford & Capps, 2018; Lederman et al., 1997; Mork et al., 2021). One proposed solution has been to provide experiences with more hands-on authentic science investigations (Bowen & Roth, 2005; Kolbe & Jorgenson, 2018; Windschitl, 2004) participating in authentic science communities with science researchers (Bowen & Hembree, 2025; Sadler et al., 2010; Morrell, 2003; Mesci, Schwartz & Pleasants, 2020; Wilcox et al., 2024). Taking this approach results in improved understandings of the Nature of Science (NOS; Nouri et al., 2021) and in those teachers using a more inquiry-oriented practices in their science teaching.

A considerable amount of research work has been conducted on the difficulties individuals have using graphical representations of data and how to address that (see Binali et al., 2024; Stephens, 2024; St. Clair, Stephens & Lee, 2024; Bowen, Bartley & Melville, 2025; Berg & Smith, 1994; Leinhardt, Zaslavsky, & Stein, 1990; Preece & Janvier, 1992). Students in undergraduate science programs lack experience with constructing graphs to represent data, which then leads to difficulties in graph interpretations (e.g., Bowen, Roth, & McGinn, 1999), consequently it should be unsurprising that science teachers have few personal experiences engaging in scientific practices or participating in research (Schwartz et al., 2004; Windschitl et al., 2008) or that PSSTs have difficulties with data interpretation (Roth, McGinn, & Bowen, 1998), which extends into aspects of collecting, summarizing, representing, and drawing conclusions from data in their own study (Bowen & Roth, 2005).

To make sense of how this situation arose with science program graduates and how we attempted to develop PSST competency with the practices of science, including data interpretation and representation, in this paper we draw on Bourdieu's theory of practice (1990, 1997). Practice theories focus on *legitimate peripheral participation* in everyday activities (Lave & Wenger, 1991). Here, "legitimate" denotes that the activity is one that is the "real McCoy" relative to disciplinary practices; "peripheral" denotes that the levels of participation vary according to the person's status as a newcomer or old-timer. This LPP perspective therefore suggests that participation in lectures best prepares students to participate in lectures and in assessment practices that parallel lectures (e.g., written exams). In other words, undergraduate studies prepare science students to participate and be successful *in* undergraduate studies; therefore, the earlier noted problems of recent science program graduates with tasks requiring them to collect or interpret real data should be of little surprise. In this study we address the research question "How does participating in a long-term inquiry investigation influence the data interpretation practices of preservice secondary science teachers?"

Research Setting

Participants

Student participants, preservice secondary science teachers (PSSTs), were in a secondary-level biology methods course conducted by the first author. The majority of PSSTs in the course had a BSc degree in biology, although a few had only a "minor" in biology (defined in this case as three full-credit biology courses). At the conclusion of their long-term independent inquiry project, after PSSTs had drafted and submitted their final report on their project, a research assistant conducted interviews with PSSTs who had volunteered to participate in our research project about their inquiry investigation work during which they could demonstrate their interpretation of data from their project (and also that of others).

Course Context

As a normal part of their assigned work in their secondary biology methods course PSSTs conducted a five-month independent inquiry project (involving 2 to 3 PSST members on each project) on a biology topic. The inquiry investigation assignment had only a few stipulations, the main of which were:

(i) PSSTs could not conduct experimental studies with vertebrate organisms, including humans, although observational studies of vertebrates might be acceptable.
(ii) PSSTs were encouraged to work on research projects utilizing only the types of equipment found in "typical" high school science labs in their local jurisdiction.
(iii) PSSTs had to work on a project for which scatter-plot representations were possible in the final discussion of the research question(s); that is, studies should be correlational in nature.

PSSTs were also encouraged to work on projects in topic areas different from those they saw as their academic "strengths," so that they could enrich their science content background for teaching (however, given the varied academic backgrounds group members, it was more the norm to have at least one group member in each project with at least some academic background in the topic area within which they were conducting research).

Data and Interpretations

The data for this paper includes transcripts of interviews conducted with the PSSTs as well as various textual resources. One-hour interviews were conducted with a total of seventeen PSSTs and the course Teaching Assistant (TA) by the research assistant. Three PSSTs participated in interviews mid-course when they had completed their data collection but prior to formal analyses, and again at the end of the year when they had completed and submitted their report. At the end of the year, after the research reports on the five-month project were completed, other PSST participants were solicited; fourteen more PSSTs from the class volunteered to participate in a research interview. During the interviews, PSST participants provided analyses of data/graphs from several sources (textbooks and journal articles, including the representation from the Lost Field Notebook (Roth, McGinn, & Bowen, 1998) problem described below), either individually or in pairs. PSSTs then discussed their inquiry project reports and provided interpretations of their findings.

At the end of the school year PSSTs were also asked to voluntarily provide reflective notes on the conduct of their project work, the problems they encountered, how they overcame them, and so on. When this data was summarized, the PSST histories were additionally coded as being "Natural Science/biology majors" or "non-biology majors" (in which case, they were in the class as their second "teachable" because they had taken three or four undergraduate biology-related courses). Each of those two groups was respectively represented in the same proportion in both the written responses (20:11) and in the interviews (11:6). Additional project-oriented written resources entered in the data corpus included: (i) the PSST project proposals submitted in September, (ii) an interim progress report submitted by the PSSTs in November, (iii) the final project report submitted by PSSTs in February, (iv) class web-based discussion board comments (PSST peer-to-peer discussions), and (v) instructororiented email inquiries (sent from individual PSSTs to the course instructor). The TA for the course also kept notes of her interactions with the PSSTs about their project over the year in her "work diary" and these were also entered into the data corpus.

Finally, there were two other non-project related written resources which were used to contextualize and make sense of the comments made by the PSSTs in their submissions and interviews about their inquiry projects. At the beginning of the academic year, PSSTs participated in two tasks to elicit their written graph/data interpretation competencies. The first task involved interpreting data presented as the "Lost Field Notebook" problem (Roth, McGinn, & Bowen, 1998). The LFN problem depicted a map with data recorded on it (density of brambles, expressed as "Percent Cover," and light intensity, expressed as "foot-candles") and a written narrative stem describing the source of the map (a grade 8 students field notebook) and what her interests were. The second task included a high-school level, standardized test item related to graphing (GCSE Item #4; in Hassal, 1988).

For the analysis conducted for this paper, the data corpus included all of these PSST resources ($N = 31$ for written datasets, $N = 17$ for the interview datasets) and the data collected from the TA. Our analyses of the recorded video interviews and student writing drew on various methodological approaches, specifically Interaction Analysis (Jordan & Henderson, 1995), constructivist grounded theory (Strauss & Corbin, 1990), and thematic analysis (Braun & Clarke, 2006).

Consistent with Interaction Analysis, in examining and analyzing the data set we first independently viewed transcripts, video, fieldnotes, the text of web-based discussions, and other materials and constructed written assertions from those. Responses to the LFN data interpretation problem (both written and in interview) were coded, enumerated and tabulated utilizing a previously published categorization scheme (Roth, 1996) in which responses to the "Lost Field Notebook" problem were coded as "Mathematical" (as a scatterplot graph, averaging, ordered tables, pattern maps, or lists) or "Verbal." From this initial analysis our data were then collapsed into abstract transformations (graphing, averaging), less abstract transformations (ordered table, pattern map, list), and no transformations (language-based) according to a scheme derived from Latour (1987). Then, in joint sessions, we examined these assertions, critiqued each perspective, and examined the database for confirming or disconfirming evidence. Final claims arose from repeated iterations of these procedures.

Results

This study showed that after conducting an independent field study as part of a secondary science methods course, the number of PSSTs who appropriately analyzed data increased. We report our findings in the following four sections.

Use of Inscriptions

At the outset of the study, the preservice teachers demonstrated levels of data analytic competencies similar to those reported in an earlier study (Roth, McGinn, & Bowen, 1998). Thus, only about 19% of the participants used abstract representations on the "Lost Field Notebook" task (Table 1). In contrast to the previous study, we also distinguished between biology majors and those who did not have a strong background in natural science/biology courses. This breakdown demonstrates that there were substantial differences in the use of abstract representations between these two groups. Table 1 shows that biology majors used many more abstract representations (75% of responses) than did non-biology majors, the latter who were more likely to interpret the data using only verbal discussions of the patterns (91%). This pattern of difference between the groups does not hold when PSSTs are prompted to graph data, as on the standardized data graphing test question (GCSE Item #4), in which the PSSTs were told to draw a graph from a data table. Responses to the standardized item demonstrated that there was little difference between the Biology majors (74% correct) and the non-Biology majors (70% correct) PSSTs in correctness in drafting a graph when prompted to do so.

Table 1. Interpretations of the "Lost Field Notebook" Word Problem

		%age Responses		
		Fall Response	**Winter Response**	**Winter (corrected) ***
Abstract Representations	Biology	25%	82%	75%
	(65% of grp)	(5 of 20)	(9 of 11)	(6 of 8)
	Non-Biology	9%	50%	50%
	(35% of grp)	(1 of 11)	(3 of 6)	(3 of 6)
	Total	19%	71%	64%
	Biology	50%	0%	* individuals or groups with
	(65% of grp)	(10 of 20)		a member who used
Less Abstract	Non-Biology	0%	0%	abstract representations in
Representations	(35% of grp)			the Fall written
	Total	32%	0%	analysis were excluded
No Transformations of Data	Biology	25%	18%	from this summary
	(65% of grp)	(5 of 20)	(2 of 11)	
	Non-Biology	91%	50%	
	(35% of grp)	(10 of 11)	(3 of 6)	
	Total	48%	29%	

Although other factors may have come into play, PSST participation in their own independent inquiry projects appeared to result in a dramatic increase in the use of graphical inscriptions to make sense of the "Lost Field Notebook" problem for both the biology majors and the non-biology majors. Compared with the fall interpretation, the responses of biology majors changed from 25% use of graphical inscriptions to 75% use of graphical inscriptions, and those of non-biology major changed from a 9% use of graphical inscriptions to a 50% use (Table 1).

In the following interview excerpt, Jass (a non-Biology major) directly attributes her changed strategy to involvement in the project (following her project data collection but before her analysis).

Jass: I'm going to draw a graph. [She sketches out a graph] So we have, up to forty percent and up to fifteen hundred foot-candles.

Interviewer: Did the concept of percent cover of brambles throw you?

Jass: It did before. But now that I've seen Karen out there on the transect talking about percent cover I think I have a better handle on what it means. Still not really firm I have to say. Um. But, I mean, it's a way of measuring relative densities obviously.

Interviewer: The reason I'm asking is that I don't remember you drawing a graph for this when I gave you this problem last time

Jass: No I didn't draw a graph. I think I'm drawing a graph based on … [her field project] and needing to generate a scatterplot by the nature of the data [for that project]. Um, cuz it would give me a better visual representation about what is going on. I'm quite sure I didn't use a scatterplot last time. I feel like I've sort of re-connected with the parts of my formal science education than I was at the beginning. You know?

Interviewer: I'm not saying it's the right or the wrong way to go about it. But it's a shift in what your practice was before.

Jass: Well, I felt, last time I felt like I had some sense of the data but not really firm, so I was feeling a little bit like I was sort of blindly feeling my way or whatever… Yea, there's a general trend. And I…huh...I almost want to draw a line right there. But it's been a long time since I've drawn a graph. There seems some linearity along here. Where are these points [on the data map]? So let's see. Thirty at five hundred; and twelve hundred at forty…

In addition, although the term "percent cover" may seem unambiguous to biologists or biology teachers, Jass indicated that she had initially struggled with the "Lost Field Notebook" problem because she was unfamiliar with the terminology; her experiences in the field collecting her own data helped ground her understanding of the components of the "Lost Field Notebook" representation and thus enabled her to bring more abstract representation tools to the problem. Many PSSTs in their interviews suggested that their problems with not having enough "context," not knowing how the data were collected or more specifically how the research depicted in the "Lost Field Notebook" problem was conducted, interfered with their interpretation of the data.

The Need for More "Context"

In fact, the only two biology majors who did not provide a scatterplot representation in the interview at year-end (Danni and Evonne; although both did individually in the earlier written submission) explained, after much discussion, that they were unable to provide any interpretation because of the lack of information about how the study was conducted and other contextual information they thought was necessary. The following excerpt details a conversation between Danni and Evonne about the collection techniques used to collect the "Lost Field Notebook" data, and illustrates how their interpretation is confounded by their lack of knowledge about the specific practices.

Danni: I would just say that I couldn't draw any firm conclusions just because–

Evonne: I’m even wondering what helps. Knowing how plants grow, increase the light and they grow really long and they’re not very dense. Less light because they’re small and they’re really dense. I just went to the conservatory.

Danni: Yeah. I was there too.

Evonne: Without her notes we don’t know that they were all taken on the same day. For all we know she had a couple that were taken on a very sunny day and maybe some of them were taken on a overcast day.

…

Evonne: Do you know what would make it more valid to me. If she, remember what we did, take section, take a hula-hoop. Throw it in here. From that say it’s only forty percent coverage in there with that amount of light. Same hula-hoop in that area...you know.

Danni: That could be how she arrived at the thirty, forty-percent coverage for each area. But we don’t know. … That’s another thing that’s missing, we don’t know how she arrived at that thirty percent. Was it taken from one estimate? Or was it several measurements?

Ultimately, Danni and Evonne decided that they could not make any decisions about what patterns may exist in the data because they were not presented with information about the nature of the area or the practices used to collect the data. Although most groups expressed that they wished they knew more about the data collection methods, Danni and Evonne constitute a negative case (as in Guba & Lincoln, 1989), as they were the only two who felt as though the lack of information impeded drawing any conclusions.

Bringing External Factors into the Interpretation

In an ecology-related question, such as that posed in the “Lost Field Notebook” task, interpreting the scatterplot alone does not illustrate that one understands relationships in the natural world. Such single-factor comparisons (such as comparing light levels to plant density) represent perspectives on making sense of the natural world (such as that used to manage cod stocks on the East Coast of Canada in the 1970’s & 1980’s; Finlayson, 1994) that are now considered unrealistic. Thus, another indicator of competency with understanding relations in the natural world is in the use of relevant and appropriate theories, concepts, ideas or observations from the natural world to help make sense of inscriptions. From that perspective, there also was a substantial increase over the year in “contextual information” or other ecology-based elements brought into discussing the “Lost Field Notebook” problem by both the biology major and the non-biology major groups (Table 2). This is consistent with the results of other studies showing that conducting fieldwork investigations gives rise to an increased articulation of the perceptual field (Roth, 2003); that is, investigators see more and more detail, which then allows them to state and control an increasing number of variables. Furthermore, other elements of the course dealt with issues which related to ecology problems and this, combined with the understandings about the complexity of relationships developed in their own work, probably contributed to their interpretations. The discussion between biology majors Danni and Evonne illustrate bringing elements “outside” of the graph (drawing on their own experiences conducting research) into their discussions.

Danni: We don’t know what anomalies are there. We don’t know if there’s a pond in here.

Evonne: That's what I mean, that's what I'm thinking. What is the area really like?

Danni: There's not enough information.

Evonne: I'm just wondering if you can reach any conclusions with that.

Danni: (???)

Evonne: Cuz I'm not aware of what's really in this area. (Danni: yeah) What could be in. Remember when we did that biomass study. And we had that worn out path area. (Danni: Yeah)

Danni: Well we had what we called anomalies, because we had that man-made path. The man-made travel area. We cordoned that off and didn't count it because it was an anomaly. This [map] doesn't show the presence or absence of any anomalies.

Evonne: Yeah, that's right.

This excerpt illustrates both their use of their own experiences to make sense of the inscription, as well as the continued difficulty they faced in drawing any conclusions without the further contextual information they felt they needed.

Table 2. Responses That Considered Other Biotic/Abiotic Factors

	Fall Response	**Winter Response**
Biology	50% (10 of 20)	91% (10 of 11)
Non-Biology	55% (6 of 11)	83% (5 of 6)
Total	52%	88%

Other PSSTs also considered other physical features of the landscape that might have resulted in the inconsistencies between the density of brambles and the amount of measured light. One pair of PSSTs postulated that the high density of brambles in one area occurred because "Maybe this is a stream, a stream running along here, and that's why those (pointing to a high value) are so high." Another pair suspected that the measured results could best be explained by the presence of a ridge drawn diagonally across the map. (Interestingly, their hypotheses corresponded with the actual setting where eighth-grade students had collected the data represented in the map.) Other factors which might be influencing the findings were also suggested by various PSSTs, such as moisture, other competing species, consuming animals, soil chemistry, soil type, soil quality, soil fertility, weather, drainage, and exposure (during the written interpretation in the Fall), and ponds, soil, rock, trails, streams, succession (other plants), overstory, soil, substrate (during the interview interpretation in the Spring). There appeared to be more examples in the interview than in the written interpretation, as well as many examples of PSSTs' experiences in other settings (which were not present in the written interpretation). A simple explanation might be that these later explanations were more detailed because the interview format afforded such expansion. However, what is notable about these interpretations is that they differed considerably from the interpretations provided by university science students during interviews (Roth & Bowen, 1999). That study found that "characteristically, and in contrast with those who had research experience, none of the examples used were based on natural populations as one might expect from ecology students in a course dealing with non-human populations" (p. 193). Instead, the PSSTs in this current study, more particularly in their interviews, provided examples that were more consistent with those we were provided by practicing scientists. They used their speculation and experiential resources to elaborate the relation between graph-as-sign and familiar things so that there was a tangible linkage between the real world from where the data was collected and the mathematical form (as represented in the graph).

Supporting Argumentation

It has been suggested that "the mastery of academic subjects is the mastery of their specialized pattern of language use" (Lemke, 1988, p. 81). In science, this means appropriating and adopting the discursive strategies involved in making and supporting claims (as making claims is at the core of the generative nature of science). It is impossible to ground scientific claims in observation alone, because observation is itself implicitly theory laden (Hodson, 1986). Nevertheless, claims in science are often grounded empirically, and the rhetoric to support these claims often draws upon various observational evidence to make those claims. One such characteristic form of evidence is to imbue one's rhetoric with direct reference to the observations that have been made about a phenomena, and it is standard discourse amongst scientists to provide interpretations of graphs that make specific reference to specific data points and trends. An examination of the written interpretations of the "Lost Field Notebook" problem suggest that there are substantial differences between the rhetorical practices of PSSTs who were biology majors and those who are not. Of the 20 biology majors in this study, fifteen (75%) used some form of abstract representation to try to order and make sense of the data, and made reference to it with their claim; a further three made specific reference to data when constructing their claim. Thus, 90% of the PSSTs with a biology major used discursive strategies that, to some degree, are characteristic of those used in science discourse when making a knowledge claim. Of the eleven non-biology majors, on the other hand, only one used some form of abstract representation to interpret the "Lost Field Notebook" data, and only a further three made a specific reference in their claim to numerical data to support their argument. In total, therefore, only four of eleven (36%) of the non-biology majors used characteristic science discursive strategies normally used in science to make knowledge claims.

The Course Teaching Assistant

The course teaching assistant was a high school biology teacher on education leave to conduct her graduate work – assigned to act as a resource and to provide support for the investigation activities carried out by the PSSTs. The course TA reported that PSSTs had considerable difficulty in framing research questions that represented covarying relationships which could be represented and analyzed using scatterplots. She also reported that some PSSTs felt this stipulated requirement was unreasonable. In part, her responsibility was to provide feedback to the PSSTs on their project proposals, including ensuring that they met the stipulated requirements of the assignment (as described above). In her "work diary" she noted that many initial project proposals dealt with categorical comparisons (such as could be depicted in bar charts), and that several PSST groups required several attempts at developing a project with co-varying variables (as was an assignment requirement). She described many of the initial PSST project ideas as "mundane biological questions," and indicated that she felt that they reflected those types of projects engaged in by the PSSTs themselves when they were in high school (despite having studied science in university). Although the TA comported herself professionally when interacting with the PSSTs scaffolding them towards choosing an appropriate project, in person with the instructor she repeatedly expressed frustration at both the PSSTs' lack of creativity and the (in)appropriateness of their projects (compared to the requirements). Based on her own teaching experience – 5 years as a science department head, 15 additional years teaching science – she expressed that the PSSTs were doing projects that were less challenging and inferior to those done by her own senior-level high school biology students. She frequently declared that she was "shocked" at the low levels of "competency," "enthusiasm," "sense-of-wonder," and "interest" in science that the PSSTs in the science methods course initially brought to their projects.

Discussion and Implications

Evidence from this study suggests that several aspects of discourse over and about graphs is altered through participation in an extended immersion inquiry project. Previously, a pilot project in a methods course with similar short-term investigation activities as this course and with only a short-term independent inquiry project suggested that improved competency with using and interpreting graphical inscriptions did not arise from a short-term inquiry project (Bowen and Roth, 2005). This current project suggests that there are three positive outcomes from engaging in a long-term inquiry project. (1) There was an improved canonical use of inscriptions as demonstrated by a higher use of abstract transformations. (2) There was an increase in the use of external referents (in the interview, relative to both the written inscription and previous interview studies). (3) There was an increase in the use of personal experiences to make sense of the components of the data problem and to interpret the relationships. All three of these suggest that there was an improvement in competency at using inscriptions as a result of participating in the long-term inquiry project (along with other aspects of the course).

At the same time, the differences between the data interpretation practices of biology majors and those of non-biology majors are revealing. There were substantial differences in practices with interpreting data between these two groups, although both did show improvement (however, the latter group is small in number and therefore claims are only tentative). In most cases, Non-biology majors did not default to disciplinary practices unless prompted to do so (including three interview participants who did not construct a scatterplot until prompted, after they had decided to end their interpretive efforts). Apart from the differences in data interpretation practices, Non-biology majors also did not construct arguments drawing on the types of rhetorical devices, such as numerical referents, that are characteristic of knowledge claims in science. These findings provide interesting resonance with those of Windschitl (2002, 2004), who reported that students in his classes with more experience in science (such as science "majors") prior to engaging in his course-based inquiry activities were more likely to engage their own students in inquiry activities than were those with little experience in science (such as non-science majors). We are left to wonder from this if familiarity and comfort with the inscriptional practices embedded in inquiry activities perhaps underlie Windschitl's findings of a tendency to promote inquiry with those with more science experience.

How are we to make sense of these results? Data, maps, and the associated story-stem in the "Lost Field Notebook" problem (see Roth, Bowen & McGinn, 1998) all acted as signs for various interpreters. For scientists, graphs and data act as signs that point to experiences they have had in their own research or travels. When interpreting a graph or data, scientists go back and forth between signs and experiences to construct an understanding of relationships between variables. Undergraduate science students possess fewer experiential referents, and therefore have fewer resources to draw upon for constructing an interpretation. Participation in the long-term inquiry project (and in other activities in which investigations were being done) provided them with at least two resources. First, participation in the inquiry investigation provided the PSSTs an opportunity to make sense of their own data by drawing on those experiences that were part of engaging in the project (and the course). Second, the activity then provided a set of external referent cues that the preservice teachers could use to help engage with, and make sense of, the signs present in the "Lost Field Notebook" data problem. Through the presence of more of these external referents, they had more resources to draw on to make sense of the problem and thus had more success doing so.

The interviews suggested that those PSSTs who had most difficulties with the initial written graph interpretation assignment were also the same PSSTs who struggled with the design and conduct of a correlational study (and who often suggested that implementing this type of activity with high school students would require the use of guided, rather than open, inquiry projects). The interpretive practices engaged in by the biology majors reflect three years or more of enculturation to disciplinary practices within their program, much of it tacitly, as opposed to explicitly acquired knowledge. Given that licensing authorities often consider a "minor" (or even less) in science as sufficient for teaching high school science, it is difficult to know how to help other PSSTs with less of an academic science background to develop these perspectives, although there was some progress with the approach adopted in this study.

As the TA´s comments indicated, implementing an open-ended inquiry project as part of a secondary biology methods course in a faculty of education meets considerable resistance. This resistance seems to arise from several directions. PSSTs in the course initially felt that they already knew science, that they already knew how to do science. Many were subsequently astonished to find out that they actually had little experience asking a science question, and often found it quite difficult to do so. At first, many PSSTs wanted to engage in the types of studies common to their own high school experience, and were tremendously resistant to moving away from cook-book style investigations towards actually dealing with some unknown; they often did not want to deal with any type of investigation whose results they could not confirm by reading some resource such as a textbook, journal article, or web page. Given their experiences in high school and undergraduate studies this is understandable. For some PSSTs, project proposals were revised, and revised again, until they were engaging with a problem that was reasonably but not overwhelmingly challenging and whose answer was not immediately apparent. Is that invested effort (by the TA and the course instructor) worth it? Quite a number (but not all) of the PSSTs who were initially resistant to engaging in the project also reported, by the end of the year, that the exercise was one that, surprisingly to them, did have considerable value even if that value was in better understanding the problems that their own students will struggle with in doing such projects. Even PSSTs who conducted projects which they considered unsuccessful often felt that they learned a substantial amount about doing science work from the activities and stressed that they would do these sorts of activities with their own classes.

Despite the resistance to conducting such long-term investigation projects we feel they are a valuable activity because they result in both an improvement in working with data and graphs, an improved orientation towards conducting inquiry investigations with their own students (as also noted in Bencze & Bowen, 2009), and an improvement in discourse practices discussing data (also see Bowen & Hembree (2025) where this was also reported for teachers participating in a multi-summer research experience with field researchers). PSSTs often lack experience in conducting authentic inquiry investigations that have the extended temporal and community aspects of professional science, and providing them such an experience in their methods courses appear to have positive learning outcomes both with regards to their own skills and knowledge and their orientation to involving their own future students in similar types of activities.

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