Forum for Education Studies 2025, 3(3), 2997.
https://doi.org/10.59400/fes2997

Article

Stories from and of the field: Developing teachers' discursive practices of science

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CITATION

Bowen GM, Hembree P. Stories from and of the field: Developing teachers' discursive practices of science. Forum for Education Studies. 2025; 3(3): 2997. https://doi.org/10.59400/fes2997

ARTICLE INFO

Received: 24 March 2025
Revised: 28 May 2025
Accepted: 3 June 2025
Available online: 5 August 2025

Abstract: Graphs and data tables play a central role in the formation and communication of scientific findings. Competent graph users interpret graphs by understanding the limitations of the representing role they play and other "real world" factors that may influence depicted relationships, using personal experience to contextualize unfamiliar graphs. This suggests that improved competency with using data inscriptions (i.e., data tables, graphs, maps, drawings, illustrations, and pictures) develops as one accumulates a repertoire of research stories that can be used to support interpretations of graphs and data. This study examines the discursive practices of teachers—how they talk, what language they use, and what they gesture towards—while discussing academic posters representing the research work of field biologists they did fieldwork with. The data suggest that the teachers developed rich "stories" drawn from their field experiences, which they used to describe their participation and to contextualize the findings that emerged from the field study. However, despite a preponderance of graphs and tables on the posters, they made few direct references to them. We suggest this occurred because the teachers had participated almost exclusively in the data collection aspects of the research and not in the generative claim-making part of the research. Nevertheless, the teachers' narrative stories of their fieldwork suggest that they appropriated many of the discursive and research practices of scientists through developing their own stories-from-the-field—"Stories of Me". They can relate these stories to their own students as firsthand narratives demonstrating nuanced understandings of the practices of real-world research and also use them as a foundation for planning inquiry activities for their own students. We conclude that more participation in the generative, claim-making aspects of science research might further enhance the ways in which teachers discuss research and research findings.

Keywords: RET; field stories; graphing; science literacy; ecology; fieldwork

"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 have been struck by the extraordinary obsession of scientists with papers, prints, diagrams, archives, abstracts, and curves on paper" [1] (p. 15).

1. Introduction

Graphs and data tables play a central role in the formation and communication of scientific findings [1,2]. Competent graph users interpret graphs with an understanding of the limitations of the role graphs play in representation, as well as taking into account other "real world" factors that may influence the depicted relationships. It has been widely argued that science teachers need to have more comprehensive backgrounds in science practices and skills [3–6] with more hands-on experiences with authentic science inquiry and science communities, which may lead teachers to adopt more inquiry-oriented practices in their own science teaching [7–9]. Other suggested solutions include requiring stronger science backgrounds [10,11], undergraduate research experiences [12,13], improving their Nature of Science (NOS) background [14], and involvement with scientists in their research projects [15]—expectations for teachers present in other countries [16]. In this case study we examine the outcomes from teachers working with scientists on their summer ecology field research over several years.

Science teachers are expected to understand the knowledge and practices of science [17,18] and to develop their own "students' skills and dispositions to use scientific and engineering practices to further their learning and to solve problems" [19]. One might expect that accomplishing this would involve having experience and practice with scientific skills beyond that which is propositional, given that "…fluency in scientific practices develops from continuing and extensive research experiences", which has led to calls for reform of undergraduate science education to provide more of these experiences [20–22]. Over and beyond this, teachers need real-world graphical analysis skills to effectively address the needs of their students in that area [23–25], the development of which is complicated by disciplinary variations [26,27].

Beyond the acquisition of skills and practices, another framework for understanding science as a discipline is that of the Nature of Science (NOS), which could be developed by engaging teachers in authentic research experiences. In education, NOS is often understood as propositional knowledge about the values and assumptions inherent to scientific knowledge [28] that contribute to an interpretive framework [29] for making sense of findings arising from inquiry investigations (or science "facts" as some call them). NOS understandings include aspects of the philosophy, history, sociology, and psychology of science addressing issues such as the tentativeness of scientific knowledge, the role of logical arguments, testability, the role of theory, and record keeping [30,31(Appendix H)]. Developing teacher NOS understandings has met with mixed success, particularly when it comes to influencing their classroom practices. Abd-El-Khalick [32] has argued that NOS needs to be foregrounded so that students actively think about it, rather than just engage in activities that accurately reflect it, suggesting using an explicit-reflective framework. Various authors have concluded that it takes more than a single course with an NOS focus to result in changes in NOS-related practices in classrooms [33–35], although some have reported positive changes [36]. Recently some researchers have suggested that there are problems with the image of science that NOS presents in that it privileges certain ways of knowing [37] and that it also needs to be complemented by developing an understanding of the Nature of Scientific Inquiry (NOSI; [38]).

For the most part, science teachers have few experiences conducting research or engaging in scientific practices [38,39] beyond those of the typical confirmatory "lab" activities encountered in their undergraduate studies [40]. Consequently, they have had little opportunity to develop these practical science skills or conceptual frameworks (i.e., NOS) to help guide investigation practices in their own science classrooms. Many researchers have suggested that more hands-on participation in authentic scientific research practices might help science teachers develop a more robust understanding of the practices of scientists [41–43].

2. Theoretical background

2.1. Learning from participation in authentic settings

Various "research experience" approaches have been used to develop and enrich teachers' understanding of the socio-cultural practices of science, including elective or science "methods" courses, summer research seminars, and site visit participation with scientists [41,44–48].

Some studies have reported that Research Experiences (RE) influences teachers' perspectives on their teaching and sense of self. Rushton and Reiss [47] concluded that REs helped teachers develop a professional identity that included teacher, scientist, mentor, and coach with positive impacts on their professional self-efficacy as they adopted a professional identity described as "teacher scientists". Valente et al.'s [49] review on teacher engagement with research experiences led by scientists concluded that these experiences changed teachers' perspectives on research—similar to the outcomes reported in Sadler et al.'s earlier [50] and broader review of the literature. Sadler et al.'s review noted that research experiences improved science content understanding and developed more positive attitudes towards science and research but concluded that results were mixed when it came to influences on science teacher practices. From their review of the literature, Valente et al. [49] concluded, "…current research is limited in terms of identifying the features of the RE that play the biggest role in the learning process." (p. 6) noting that "there are still several issues that require further investigation." (p. 6) with respect to outcomes from Research Experiences for Teachers (RET). From their own subsequent study, Valente et al. [49] did not find that the improved understandings of, appreciation for, and knowledge about inquiry that occurred resulted in increases in inquiry in teachers' own classroom teaching, similar to the conclusions reached by Brown and Melear [44]. In contrast, Wakefield [51] concluded that only in some highly structured circumstances can RETs result in changes in classroom practice.

Engagement in RETs often draws upon and reflects two sociocultural frameworks for understanding enculturation to practices, specifically those of Legitimate Peripheral Participation [52] and communities of practice [53,54].

Disciplines, such as science, share practices, interests, social mores and ways, and other cultural norms—varying by discipline and even sub-disciplines—forming a Community of Practice (CoP). CoP has three crucial characteristics: The domain, the community, and the practice, with the latter constituted by a shared repertoire of resources including experiences, stories, tools, and ways of addressing recurring problems [54].

People learn as they participate in "everyday" activities, the term everyday reflecting activities of the community/communities of practice within which individuals are embedded. If one is participating in a community of scientists, then those everyday activities would involve those activities and interests which scientists engage in within their community of scientists. New community members participate in various ways with the established practices of the community. Lave and Wenger [52] suggest that for newcomers to a community these practices are initially peripheral (i.e., not central to the practices) but legitimate (i.e., authentic within the community context in that they are practices the community actually engages in), a process known as Legitimate Peripheral Participation (LPP). Then over time, as experience and competency are gained, the practices engaged with become more core to the community's practices. In a theory-of-practice sense this can be seen as a move from naïve doxa towards an orthe doxa where one both develops the skill of the community as well as adopting a more critical disposition towards one's community and its practices [55,56]. When a community member is consistently engaging in core practices they have become an "old timer" within the community and are firmly established as a community member. This acquisition of scientific practices through LPP can be understood as acquiring "a set of dispositions that structure perceptions of and actions toward the world, but are themselves structured by the experience in the world" [57] (p. 20).

2.2. Inquiry, story(tell)ing, graphs and data

Considerable research in the sociology of science has reported that inscriptions (i.e., primarily data tables and graphs, as well as maps, drawings, illustrations, and pictures) play a central role in the practices and narratives that form and communicate scientific findings [58]. Although they play an obvious role in representing data, inscriptions also both constrain and summarize data in ways that "lose" some of the information contained within the data. There is a substantial body of research on the difficulties individuals encounter when using and interpreting graphical representations of data [59–61]. GMB's own past research has reported on the ways in which preservice teachers engage in inquiry and data analysis practices that are often inconsistent with the canonical practices found in scientific research [7,41,62] and, for that matter, most undergraduate science courses, which has been attributed to their lack of familiarity with data interpretation and natural settings [7,40,63]. He and others have posited that these difficulties contributed in part to some of the resistance to conducting classroom inquiry activities [39,40,64].

One way to develop competency at inscriptional and inquiry practices is to do so in an "authentic" setting by engaging in real-world, long-term scientific inquiry projects [7,65,66]. Drawing on the idea that science itself, and the multi-semiotic texts of science (as described by Latour at the opening quotation [1]), are in themselves a "story" [67–69] this paper is an examination of the narratives [70,71] related by teachers about their participation with scientists conducting field research at a remote field site.

Stories derived from lived experience—and therefore storytelling—help us make sense of the world [72] and are one of two main ways of thinking and knowing, which serves the purpose of sharing meaning between people [73], as stories implicitly and explicitly teach about culture and sociocultural practices, what is acceptable and what is not acceptable in that culture [74,75]. Stories about science and experiences with science permeate popular culture following our graduating from schooling in many ways. Countless movies demonstrate aspects of science and its practices, including “savior” aspects (e.g., “Armageddon” (1988), where earth is saved from an asteroid), the persistence of scientists in investigating problems (e.g., “The Man in the White Suit” depicting the invention of synthetic fiber (1951)), and ethical issues of science (e.g., “Medicine Man”, where searching remote rainforest regions for antibiotic progenitors caused the death of local indigenous people (1992), and “Oppenheimer” about the creation of the atomic bomb (2023)), although there are issues with how accurately science is portrayed in this form of media [76]. Newspaper reports about science are also stories crafted to a particular formula, although again there are issues with the accuracy of what is portrayed about the practice of science in news media representations of science even predating Covid-19 coverage [77].

The idea of discursive practices, developed by Foucault, goes beyond the mere use of language (i.e., the correct words) but also incorporates sets of practices and interactions that relate to how knowledge is formed, the power relations within that, and the construction of social reality [78]. Telling “stories” about activities one has engaged with is a discursive practice. Several researchers have reported on the value of using narrative stories to teach about science [79–81], although there are several issues with this portrayal of science as well [82], especially from the aspect of “heroic” stories. Milne [79] argues that heroic stories misrepresent science in that they “focus on a hero of science who single-handedly contributed to the development of science.” (p. 175), which could therefore lead towards a “savior” expectation (that we will be “saved”; the problem will be solved by the right person doing the right thing at the last moment). The critique of savior movies, for instance, a term that often applies to inner city and racial issues [83], applies equally to many stories about science/scientists (and saviorism in those) in that they misrepresent relations and practices between insiders and outsiders.

Science stories are often conveyed secondhand (from the ‘hero’ to the narrator) or thirdhand (passed down to others even further removed from the original event). These types of story constructions—whether in textbooks, documentaries, or from teachers—can have the same accuracy issues as the telephone game played by children in many Western countries (see https://en.wikipedia.org/wiki/Telephone_game) in that the longer the chain of description from the first event to the final recipient of the description, the less accurate the end description often is (the end of which in storytelling is often idealized and cleansed so that it little represents the actual event). In the (re-)telling of science stories, this results in eidetic (i.e., idealized) images of science [84] that remove the messiness found in actual scientific practice [85] and which confound effective understanding of that science [7,70].

The biology field research project in which teachers were immersed for this study fully represented the messiness (and hardships) of field research [70,71]. This RET, therefore, provided a rich opportunity for teachers to develop and share their own narratives about scientific practice and the findings emerging from that field research. When these teachers engaged in research with field biologists, they had the opportunity to develop their own science-related "Stories of Me" rather than the stories about what someone else did, the "Stories of Them" that are often (re-)related in schools and news/entertainment media. This paper details our efforts to understand how multi-summer RET participation by teachers at a Long-Term Ecological Research site in coastal Georgia helped them develop an improved understanding of science inquiry, data interpretation, and concepts and the associated discursive argumentation practices.

3. Research setting

Each summer over four years, the second author led a professional development program that partnered teachers with field-based scientists as collaborative researchers at a remote research station for nine days (an engagement length found to have productive outcomes with the between-season supports; [86]). In this setting, small groups of teachers (usually 1 to 3) worked alongside field biologists and/or their graduate students as they conducted their field research. Teachers engaged in various roles, including field sampling, data transcription, equipment handling (in both use and in (re)locating it at the field sites), enumeration of samples (e.g., cleaning and counting organisms at both macro and micro levels), preparation of chemicals and microscope slides, discussion of research design and modification of methods, sharing and interpretation of observations made in the field (as part of evaluating progress and methods), and so on. The research projects themselves were truly "authentic" and "legitimate" in that they were the actual, ongoing research of the biologists—the projects were not designed nor created merely for the purpose of engaging the teachers but were instead part of the overall research agenda of the lead biologists (often, although not always, university professors) and their graduate students.

The research setting facilitated social interaction between teachers and researchers on a day-by-day basis and in the evenings, which enhances the effectiveness of RETs [87]. Interactions between teachers and scientists extended beyond the field season, continuing throughout the school year as they communicated with each other about their research experiences, discussed ways of incorporating similar sorts of activities into their classroom with their own students, and continued to interact with the biologists about the research projects as the academic work on the projects progressed between the field seasons (when the scientists conducted analysis and engaged in academic endeavors such as conferences). Between field seasons, the biologists also offered feedback and suggestions to the teachers to help support developing school-based activities for the teachers' students. In addition, on some projects between seasons, the biologists also included teachers in discussions about the data analysis (although not the analysis itself), future directions of the research work, and research conclusions. This extended engagement between researchers and teachers occurred both through virtual meetings during the year between field research seasons as well as upon the teachers' return to the field sites in subsequent years.

The teacher participants in the field seasons ranged in age from 22 to over 50 years of age and evolved over the 4 years of the program as some participants did not continue and new teacher participants then attended, while other teachers returned every year. Over the years, the participating biologists also changed as graduate students completed their dissertations, researchers changed institutions, and funding priorities shifted from one area of focus to another.

3.1. Data collection and interpretation

A wide variety and large amount of data was collected for the broader data corpus across the four field seasons, including copies of the teachers' field notebooks; annotated photographs of their work with biologists; video recordings of their fieldwork and laboratory work (at the field station) and interactions with the biologists; interviews both during and between field seasons; ethnographic field notes; and so on. In addition, detailed records of the research field setting were made (including photographic, interview, and impressionistic field notes) and entered into the database.

For this study, volunteers were recruited from among the teachers participating in the fourth field season, and two were selected for recorded video interviews (time restrictions, availability, and resources limited this study to two participants). These two teachers were selected to participate in this research because (i) they each had long participation records working at this field research site (each had participated at the LTER field station for 3 years), and (ii) they represented a polarity of teaching experience. One interviewee was a new teacher who had just completed their first year of high school science teaching; their first two field seasons occurred at the end of their third and final year of teacher education. The second interviewee had 15 years of experience teaching high school science.

For this article we draw on three data sets drawn from the broader data corpus. Two of those are drawn from the dataset collected at the Long-Term Ecological Research (LTER) field station: (1) Detailed photographs were taken of posters created for science research conferences that were posted in the living area and laboratory area of the field research station, which were therefore constantly available to the teachers, showcasing research conducted at the LTER site, and (2) GMB (a visitor invited to the research site by PH) conducted video-recorded interviews with the two teacher volunteers as they discussed the academic poster depicting the research project they had participated in.

As a third data source for analysis, to provide interpretive context for the interviews with the teachers and the research poster analysis, video recordings were made of conference presentations at an academic conference of research work conducted by scientists at different field settings. These presentations were of research work comparable to that conducted at the LTER field research site, and the video recordings were used to provide a description of how field researchers discussed their research findings at an academic conference. The rationale for analyzing the posters and presentations is that most research on the use of inscriptions in science focuses on their use-in-action (as part of the day-to-day conduct of the research) and use in publications of the research [58,88] but does not focus on the intermediary role of conference presentations (either on posters or verbally), so an analysis of their usage in these settings provides a comparative context with the discussions by the teachers in their interviews where they discussed posters from academic conferences.

Interaction analysis [89] and grounded theory [90] provided the foundation for analyzing the posters, video recordings, and transcripts on the assumption that understanding and reasoning are observable in the form of socially structured and embodied activity [91]. For each data set we first independently viewed and annotated the data sources, and each of us constructed individual assertions from those. [Note: In the case of video recordings, the viewing/annotation involved viewing the video and the transcript simultaneously, noting in the transcript what gestures and motions the interviewees made while discussing the artifact they were viewing. These were reviewed as necessary when constructing joint claims]. Then, together in joint sessions, we collectively examined these individual assertions, critiqued each perspective, and (re-)examined the database for confirming or disconfirming evidence, which was used to re-frame the collective assertions. Our final joint claims arose from many such iterations of this process.

Using the above-described approach, we first analyzed photographic representations of all of the posters on display at the research site to contextualize the discursive and inscriptional resources the two teachers were able to draw on to frame their discussion of their academic research poster. Given our interest in inscriptions, we analyzed the frequency of different types used in the research posters at the LTER field station to support research findings.

Secondly, we then analyzed the video recordings of spoken conference presentations of biology research work comparable to those represented in the LTER academic research posters. The analysis of the spoken conference presentations focused on calculating the amount of time a presenter spent discussing the different types of inscriptions (i.e., text, tables, graphs, diagrams, maps, and photographs) in their conference presentation slides.

Finally, we analyzed video-recorded interviews and transcripts from the two teacher participants. Each discussed an academic research poster prepared for and presented at conferences by the field biologists they had worked with. The poster summarized and reported on the field research projects the teachers had participated in during previous summers.

3.2. Description of data and findings

Inscriptions are commonplace in science writing, as well as in laboratories and field settings where data is compiled. Consequently, they play a central role in the rhetoric of constructing science claims [58], although their use in intermediary settings, such as conference posters and presentations, is less well documented. As the goal of having teachers actively participate with field scientists in their research was to improve their overall science literacy (i.e., understanding of science practices as enacted during actual research) and discourse about those practices, it is not unreasonable to examine how the teachers engage in discussions of their fieldwork experiences and the associated inscriptions (i.e., the posters).

To provide context for the discussion of the interviews with the two teacher participants, we will first establish (a) how the scientists themselves chose to represent their research projects in conference posters with a particular focus on the use of data inscriptions (i.e., graphs, data tables, maps) and (b) what focus on inscriptions occurs when research work is discussed at a conference. Following this, we will then examine the degree to which the two posters discussed by the teachers compare to those in the overall data set.

1) Use of inscriptions in posters at the LTER site

According to the LTER station site manager (Pers. Comm.), the 13 academic posters on view in the hallways at the research center were representative of the variety of research projects conducted at the research center over the previous years, including those research projects that the teachers had participated in. Drawing on his own experience attending science conferences over the past 30 years, the first author concluded that the posters on display in the halls at the LTER field station depicted a normative cross-section of research posters at academic science conferences, in both their structure and design (i.e., their discursive style, their use of inscriptions, and the manner in which they constructed scientific claims) and physical size. Given that the LTER field station posters depicted a representation of data and the construction of scientific claims by academics from multiple institutions over several years, this representative nature is hardly surprising. As a further indication of their typicality, a comparison of the LTER posters with a stylized, idealized poster image in a handbook on communication skills for scientists (see "Preparing a Poster"; [92]) suggested that they conformed reasonably well to those design suggestions, including in their use of inscriptions and the area devoted to them, in the size and outlining of text, and in the degree of detail they offered.

Table 1. Total number of different types of inscriptions in scientific posters (n = 13) and the typicality of the posters discussed during interviews by teachers in this study.

	Number of inscriptions	**Number of posters with that type**	**Present in poster of participant #1 (Kathy)**	**Present in poster of participant #2 (Trevor)**
Pie chart	11	2		☑
Bar chart	24	8	☑	☑
Line graph	33	7	☑	☑
Scatterplot	127	7		☑
Tables	10	7	☑	
Photographs	27	6	☑	☑
Maps	29	11	☑	☑
Diagrams	17	6		
Models/flowcharts	10	6		
Formula	3	2		

Overall, the LTER posters featured a predominance of graphical inscriptions and data tables (**Table 1**), similar to those reported in formal journal publications, although the prevalence of photographs, maps, and diagrams was proportionately greater relative to the amount of text than was reported in academic journal publications [88].

Comparing the posters discussed in the teacher interviews with the overall LTER posters, we conclude that they were reasonably representative of the available LTER research posters in their use of inscriptions, particularly in their use of both high-order and low-order (i.e., more to less abstracted) graphical representations.

2) Discussion of inscriptions in biological conference presentations

While the frequency of inscriptions in the posters suggests that they play a significant role in the construction of the knowledge claims, analysis of the posters alone provides few insights into whether the discussion of research by scientists at a conference would have focused on inscriptions. To further illuminate the role that inscriptions play in presenting a research project, two hours of video recordings (comprised of 10 research project presentations) made during a one-day symposium of biological research (described in [70]) were analyzed. This analysis found that even though presentation and discussion of text was quite important (35% of the presentation time explicitly discussed text representations), discussions of visual inscriptions dominated the presentations (37% of presentation time discussed tables, graphs, or diagrams/models; maps were discussed 8% of the time; and photographs were discussed 21% of the time). On average the discussion of non-text inscriptions accounted for almost two-thirds of the time allocated to a presentation.

Overall, these two analyses of research presentations at conferences suggest that a compelling argument can be made that presentations by scientists of their research work at academic conferences have a major focus on the representation of data in tables and graphs, which thereby play a central role in the construction of knowledge claims emerging from the work. These scientific knowledge claims are constructed and discussed in conference settings using a considerable number of explicit references to data inscriptions—with more of a focus on visual, non-text representations in conference settings relative to text than was previously reported in scientific journal publications [88], reinforcing the centrality of data representations in scientific practices, as described by Latour [58].

3) Discussions of research posters by teacher participants

A) Trevor, the “new” science teacher

When discussing their participation in the research projects using the poster as a referent, the two teachers frequently gestured towards specific parts of the poster as a way of focusing the interviewer on the salient parts of the poster to contextualize their comments. To aid in interpreting the following discussion of Trevor’s gestures towards the poster during his interview, we provide a sketch representation of the poster Trevor discussed. Trevor’s poster was comprised of three text blocks, seven different graphical inscriptions, one map, and four photographs (**Figure 1**). In the beginning of Trevor’s interview about the research poster, while he was providing a descriptive introduction to the field research project it represented, Trevor gestured towards the map on the poster (see **Figure 1**) to indicate the specific locale at which sampling was conducted.

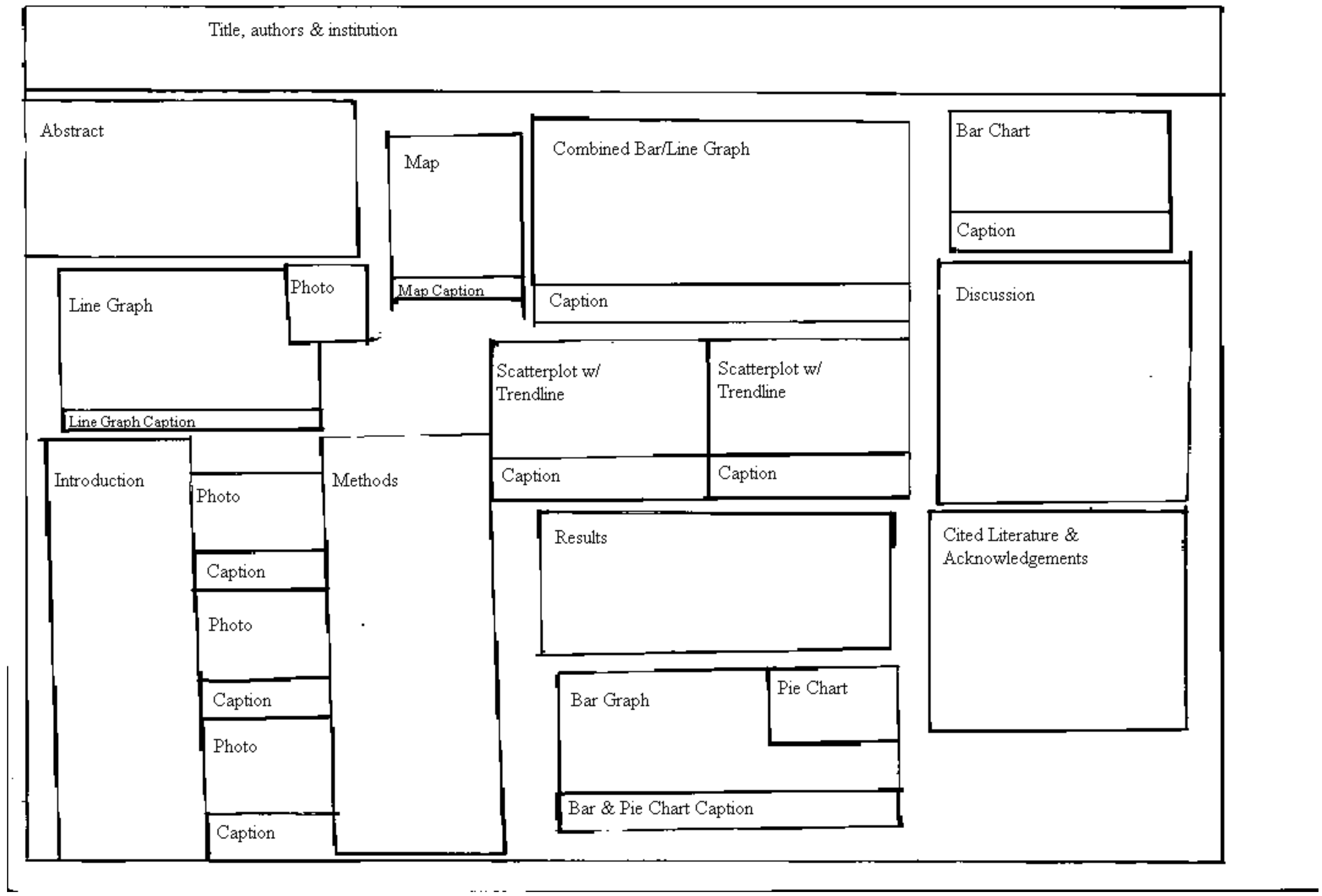

Figure 1. Depiction of poster discussed by Trevor.

"Here we went up the Duplin River, trawling for blue crab, and we trawled three or four different sites, pulled in the nets, dragged the bottom for I guess *about a good quarter of a mile* for each trawl, and pulled the nets in and separated blue crabs and shrimp." [TREVOR 040716; *italics* indicates when he was gesturing on/at the map on the poster].

In this instance of gesturing to the map, Trevor did so by pointing non-specifically at the overall map. Later in the interview, when describing the sampling locations, he used his finger to specifically indicate the areas involved in the trawl.

"*If you go, we came up, you see, there's a refuge, so we went in here and went probably further up north here 'til it starts to really get very shallow, and we'd trawl backwards, so we'd run our way up, out near the wildlife refuge area back here, and just trawl our way back, pick up and go*, and we put in over near the gas station, and I can't remember exactly where on the island the gas station is; it's over, *it's in this area over here, so it was nice*; I enjoyed it." [TREVOR 040716; *italics* indicates when he was using a finger to specifically refer to locations on the map as he was describing it].

Trevor's use of specific areas on the poster as a referent for his narration was not limited to interpretations of the map. He also made specific references to the photograph of the fisherman who helped with sampling during the year and provided a detailed description of a sampling regime by referring to a bar chart. To illustrate this, we include the following interview excerpt in which Trevor describes the types of sampling conducted by the field researcher the year before he worked with her, using gestures to reference the bar/line graph on the poster (refer to **Figure 2** while reading the quote).

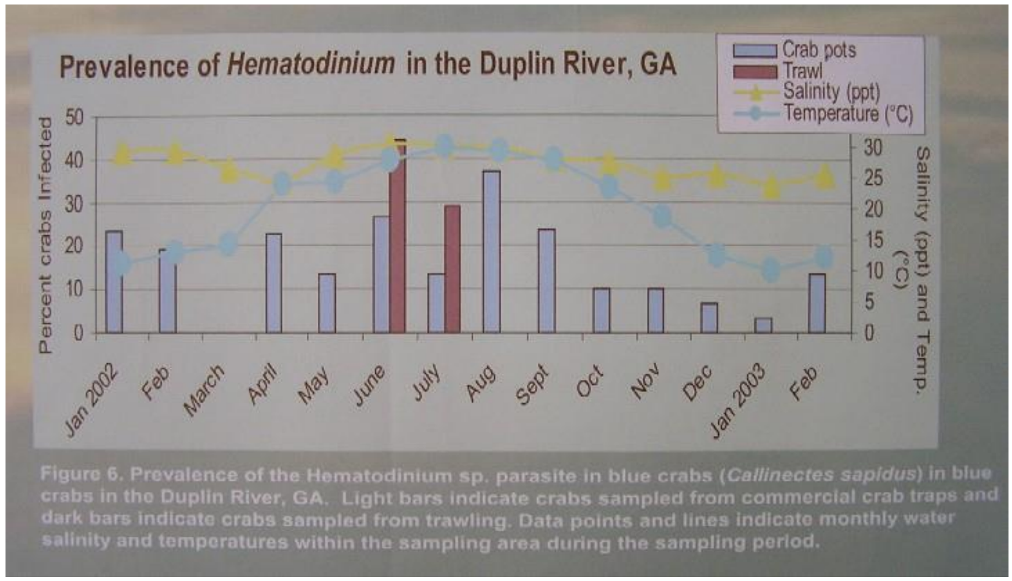

Figure 2. Bar graph used by Trevor as a referent for describing the sampling regime used by the researchers.

"But, this is the [*his fingers drift over the two line charts (one of which is for salinity) and then taps on the middle of the bar graph above them*] big thing, was the drought that we had in 2002 & 2003. Just the no rain increased the salinity big time in the Duplin, and all that infection shot way up. But if you notice, I guess she was only doing trawls [*two fingers tap twice on the June & July labels*] in June and July when she was here doing research and was picking up samples. Because I remember that she said that she would always have to drive down and go with Jimmy once or twice [*a finger taps on the lower part of the four bars preceding June/July, and then less specifically on two afterwards*] and pick up from his crab pots, which apparently is very dangerous." [TREVOR 040716].

Trevor's gestures did not seem to be intended to provide a detailed interpretation of the graph's data but rather functioned as reference points for describing the researcher's sampling activities across different times of the year.

Throughout the interview, Trevor made only a single gesture which could be interpreted as elaborating on the interpretation of a graph. This gesture occurred when he was referring to an increase in salinity being correlated with an increase in infection rates ("the higher the salinity, the more the infection"), during which he traced his finger along the line-of-best-fit, which was laid over the raw data points.

In total, Trevor gestured specifically toward (i) the map four times, (ii) five of the seven graphs on ten occasions, (iii) the poster text twice, and (iv) two of the four pictures twice during his twenty-minute interview. Apart from the exceptions detailed above, these references could be described as *point-tap* or *point-tap-tap*; in other words, they were brief, generalized gestures to focus the interviewer on a specific part of the poster or inscription as opposed to specifically assisting in the elaboration of the text of either the poster or Trevor's description (we noted that this may be because he assumed that the interviewer could interpret those inscriptions for themselves during his narrative).

Another significant aspect of Trevor's interview was how he positioned himself relative to the biologists in the research group. Throughout the interview, he made references to the field researcher in a manner that indicated that, from their perspective, it was clearly her project. However, he also identified himself as being part of the project in an ongoing fashion. Our interpretation of this arises from the following interview incidents:

(I) Trevor referred to his participation in the project using the term "we", even when discussing the project in the present tense.

(II) Trevor saw himself as an ongoing participant in the research project (even though the researcher was no longer at this LTER research facility) and looked forward to receiving future information on the progress of the project.

(III) Trevor indicated he was aware of the history of the project and the data collected even prior to his own involvement. This information was salient enough to him that he remembered it a year after his participation in collecting the data and related it as part of the interview.

(IV) Trevor expressed interest in obtaining his own samples and collecting parasitic infestation data from them to further contribute to the data collection of the research project.

From these data, we concluded that Trevor saw himself as part of an active, ongoing research project and that, although that particular field research project was no longer based out of the LTER site, part of his identity was as a research project participant in that project.

Several parts of Trevor's interview also indicated that he had developed understandings of the practice of science common to "real-world" science but much less common to "school science" (as portrayed in textbooks and classroom laboratory practices). For instance, he noted that the study of the parasitic species on crab emerged from a changing crab population reported by the crab fishery, that the field researcher generated new questions as the fieldwork progressed, collecting data beyond the original project's focus, and that those new questions emerged from inadvertent, casual observations that occurred as a consequence of collecting data for the original project (practices documented in a study of different field researchers reported by Roth and Bowen [93]). In addition, Trevor described contingencies in the field that affected the conduct of field research (so that they deviated from an "ideal" approach), such as the way in which "crabbers got really pissed off that [the university] was setting up crab traps" and that this affected the data collection approaches available to the field researcher.

Trevor also indicated in conversations with other teachers that he understood the generative (i.e., epistemic) nature of science and that reporting data and claims was an important feature of the conduct of science. Near the end of their field period, when the teachers were collectively designing a poster to represent their field experiences that season, Trevor asked, "Would it be okay if we waited until we got some of the data and tables that list the crabs and numbers from [the field researcher] and moved some things around and added them before we had the poster printed?" This question indicated that he proactively recognized the role that inscriptions play in representations of science research. Trevor wanted the teachers' posters— created to be displayed in their schools— to authentically represent their field experiences. He believed this required including graphs and claims that derived from the research at the LTER field sites. From these statements we conclude that Trevor had developed a more nuanced and robust understanding of the practices of science than that usually evident in a recent graduate from an undergraduate science program (such as described in [62]).

B) Kathy, the "experienced" science teacher

Kathy, the second teacher interviewed using a conference poster of the field research project she had worked on, engaged in discursive practices similar to Trevor's—except for one key difference. When making her gestures, Kathy frequently referred to the map, starting with it—just as Trevor did—to delineate the research question and then revisiting it multiple times to emphasize aspects of the research design and findings, and she also referred to four of the five pictures on the poster (which represented the organisms studied in the field research). As did Trevor, she also discussed some of the text explicitly by pointing at it and trailing her finger along it. However, unlike Trevor, only one single time in the 19m:30s interview did Kathy gesture towards one of the four graphs on the poster, using it as a referent for her continued interest in the project despite some of her involvement having been two field seasons ago, "…*some of this stuff was two years ago now, and I'm still interested in it*" (italics indicate when she was tapping on the graph with her finger).

Overall, Kathy specifically gestured towards the map eight different times (usually in a prolonged fashion, pointing back and forth at different locations), towards four of the five pictures nineteen times (the unused picture was not a "research" picture with a caption but was a general picture of a marsh), towards the poster text three times (all in the summary/conclusions section), and, as mentioned, towards one of the four graphs only once. However, her referring to the map and photographs was generally much different than Trevor's approach. While talking, Kathy's fingers moved back and forth, gesturing between different parts of those images to emphasize different components of the design of the project, what was significant in the organisms that were being studied, and even significantly salient aspects of the data that were collected (by indicating areas of the leaf that had been consumed, etc.).

Kathy also indicated ways in which she had appropriated practices more common to participation in authentic research. She explicitly referred to her field record book, in which she had recorded both observations and data collected in the field to find details of the study design from her participation in the project being discussed. In her discussion, she also referred to and drew connections —both in study design and in equipment comparability—between the study she had participated in and other studies with different organisms by other researchers conducted out of the LTER research station (but in different environments in the local area). Further, Kathy discussed how she was going to appropriate practices from these different studies to design a research project for her students in her school to investigate similar phenomena (although she professed to not knowing "what kind of critters, what kind of predators, or what kind of grasses I'm going to mess with, but I'll work something up"), demonstrating her ability to apply ecological principles and research questions across different biological settings. In our analysis we concluded there were similarities between her prolonged interest in investigating these issues and Trevor's interest in ongoing and further participation in the project in which he had been previously involved (which was not as amenable to transfer to a new setting as were the studies Kathy was drawing on).

4. Conclusions and implications

Most undergraduate science programs contain few activities that resemble the science environments engaged in by professional scientists (see a discussion of this in [7,70,94]) such that science teachers have little experience with the conduct of science in "authentic" settings [6,39,40,95], although there are now many recent efforts to provide research experiences for undergraduate (REU) science students (see [50]). Research into the practices engaged in by pre-service science teachers during inquiry activities suggests that they engage in inquiry practices that do not align with the priorities of reform documents [62,96]. Yet, many reform and curriculum documents encourage teachers to involve their students in activities that reflect professional science in the form of student-directed, open-ended inquiry activities in community-based "real-world" issues where those practices and many others are encouraged.

The overall goal of the LTER project was to increase the knowledge and experiences of teachers about actual science practices (both applied and conceptual) so they can use these ideas to inform their own classroom approaches. How are we to understand the interpretations of the posters by the two participants to allow us insights into the original goals?

One can conceptualize science disciplines as being comprised of a number of different, although interrelated, practices. For instance, one could adopt the perspective that central to the practice of science is the asking of questions, the operationalization of these questions (including the negotiation of what constitutes acceptable methodology), the actual collection of the data and the organization and summarization of it (using tables, graphs, etc.) in a manner acceptable to the community, the interpretation of the data to construct knowledge claims, and ultimately the integration of these knowledge claims into related scientific theories. Overlaying all of these operations is the inherent social nature of science practice [58,97,98], which means that each of these features is negotiated for appropriateness both within localized research groups and more broadly (for instance, at conferences and then in publication, where findings are accessible to others than those who attend conferences) and also temporally, as the findings are first compared to similar studies in the short term and then are used (or rejected) in developing or refining theoretical claims in the long term. As members participate in each of these settings, they will find particular discursive patterns both amongst different members (such as between graduate students and professors) and also in different settings in which the community operates [70].

In general, one can argue that this progression from observation to question to theory is a trajectory of complexity where one progresses from participation in the "real world" to forming an explanatory abstraction of the real world (**Figure 3**). This makes clear the enormity of understanding the participation of "new" members as they progress along a trajectory from "newcomer" to "old-timer" [52], as this trajectory involves the appropriation of material practices, a variety of discursive practices, and a shift from lived experience in the real world towards trying to abstract the real world and explain phenomena within it theoretically.

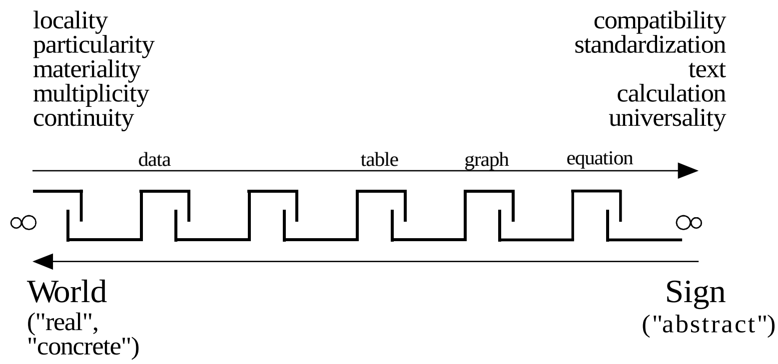

Figure 3. Movement from "world" to abstract "sign" [7].

4.1. Narratives about practice

The discussions engaged in by Trevor and Kathy with the interviewer (GMB, also a former biology field researcher) about the research posters were similar to the "field narratives" that were engaged with among field biologists in other studies [51]. In each of their cases they were not telling field stories of "others" but were telling stories about themselves—what we call "Stories of Me"—and the others they participated with. Both Trevor and Kathy saw themselves as part of the project, not as a viewer of the project. This is reflected in places other than their interviews, as the teachers (all of them, not just our participants) decided that one of the things they were going to do was complete posters to put up in their schools to show their students about the field research projects they were participating in and, as detailed with Kathy, considered plans to adapt the field research projects at the field site to projects that their own students could engage with. Collectively, this suggests that Trevor and Kathy had moved beyond the "participant narrator" role discussed by Giamellaro et al. [46], moving towards constructing an identity described by Rushton and Reiss [47] as "teacher scientists".

Enculturation into practices through LPP occurs in field settings in several ways, including the appropriation and development of field stories. In our interviews here (and elsewhere at the field site), teachers related stories to each other about their field experiences and related telling stories of their experiences to their own students. In field science these stories are not just told for entertainment purposes; they are the foundation of developing an understanding of relationships between phenomena observed/experienced in the field; they form the foundation for constructing more comprehensive discussions of inscriptions; and they are an important component of identity formation [71]. Beyond this, these stories-from-the-field are not just "war stories" of deprivation and difficulty [99] but are part of "appropriating the tacit knowledge that characterizes ecologists" [56,96].

4.2. Stories as part of moving from newcomer to old-timer

The accumulation and relating of field stories would appear to be part of the ordering of stories, from a "muddled" understanding of relationships to more canonical science discourse and an understanding of probabilistic relationships as depicted in graphs and models [63,100]. In other words, developing and telling field stories is part of the movement along the trajectory from newcomer to old-timer. Being able to engage in these stories-from-the-field demonstrates the development of a more robust understanding of science practices, illustrating movement along the trajectory from a naïve to a more informed doxa. For instance, Trevor and Kathy demonstrated an understanding of asking questions that relate to understanding broader relations in science (such as in the conceptual and methodological transference from one setting to another discussed by Kathy), and their discourse demonstrates an understanding of how to design and conduct science research studies in "real world" settings in such a fashion as to accommodate constraints imposed by those settings (such as a commercial crab fishery). Further, both their discussions resembled those of experienced practitioners discussing their work in informal settings [70,96] as their narratives about the research posters involved a considerable elaboration of stories of field experiences to enrich their discussion of the knowledge claims made in the studies. From this we concluded that our teacher participants developed a better understanding of the socially and culturally embedded aspects of scientific research [101,102] as well as a more comprehensive understanding of the Nature of Science (although we cannot claim that they have a conscious awareness of this).

The use of technical language in scientific discourse creates "a barrier between those who can speak and understand [it] and those who cannot" [103] (p. 7), especially when there is an increase in the use of jargon [104]. The multiple facets of scientific discourse and texts, their often-expository nature, and the specificities of domain-specific discourse make the formal language of science more difficult to understand [105], but the informal nature of field stories and the settings they are told in serve as stepping stones toward the appropriation of more formal scientific discourse. Scientific discourse is also multi-semiotic (involving texts, graphs, images, diagrams, tables, and so forth) and consequently differs substantially from the conversations of everyday life. Avraamidou and Osborne

[80] argue that fictional narratives, unlike the experiential stories discussed in this study, offer considerable benefits in teaching students about the practices of science—but it is hard to imagine these fictional narratives being multi-semiotic. Nevertheless, there is little reason to suspect that field stories based on personal experience would be any less effective than fictional stories, especially as teachers would be taking into account the academic level of their audience in the (re)telling and so would be less likely to use the technical language of science. Egan [106] noted that, "Teachers tell their students stories from the first day they start school" (p. 5), and arguably stories play an important role in the teaching of any subject, including science (although Egan notes they play a lesser role in more "serious" subjects). In this study teachers seemed to use the structure of the stories [72] to both develop and demonstrate their understandings of the studied phenomena/relationships—dialectically moving back and forth between their role(s), their memories of the field researchers and field setting, and the varied representations in the poster—akin to the understandings also held by the scientists.

As researchers, we are under no illusion that the stories that the teachers related to us are identical to those they would tell their own students, as any act of storytelling is an interaction between the teller and their audience whereby some aspects are highlighted for some audiences and not others [71,107]. Nevertheless, any first-hand narrative of their involvement they would tell their own students would differ from those about research that students would normally hear (i.e., stories of others). Almost all the stories' students would normally hear about science are being told at a distance, the story told by someone who the story was (also) told to; rarely would K-12 students hear firsthand accounts about the doing of science. Understandably, stories told from a first-hand perspective have a considerable capacity to capture students' interest, and they model (science) practices from a first-hand perspective [108]. When Kathy engages her own students in the inquiry investigations she discussed, she will be able to answer questions they ask from firsthand experience, with a credibility embedded in her actual practices in the field. Discourses are the central ordering practices of communities [109], and by relating her "Stories of Me" to her students, Kathy will be convincingly modeling the practices of science, facilitating and enhancing the inquiry investigations she is planning for them.

4.3. Limits of the field research experience

However, there was one notable difference in Trevor and Kathy's discussions of the posters relative to research presentations by scientists, which was seen in how both Trevor and Karen referred to and incorporated graphical inscriptions in their narratives. Despite previous evidence that a rich repertoire of stories was a necessary component of effectively interpreting graphs and data [71], it is apparent from this study that being able to draw on a repertoire of stories does not necessarily result in an interpretation of the available inscriptions actually occurring. Despite graphical inscriptions being central to the construction of claims in science and despite their own ongoing participation in the research setting, neither of the teacher participants linked the graphs on the posters to their descriptions of the field research findings in any detail, although each provided a rich qualitative description of the research findings in the two studies. Why might they not have made more frequent reference to the graph and data inscriptions? Why might such discrepancies exist? And are they important?

The setting in which the teachers participated involved data collection in both the field and at the data entry level. However, for the most part, these teachers did not participate in the specific and detailed analysis of the data that usually occurs in the months following a field season (which, one should note, is different from the observational-level analysis that occurs as one participates in collecting data in the field). It is during these after-the-field-season analyses that inscriptional representations such as those found on the poster are constructed. Thus, Trevor and Kathy presented and discussed data conclusions and summaries consistent with what they personally experienced during the field-based project work they participated in. What each did discuss, during their interviews, were the generalized "as this goes up, this goes down" type of statements related among researchers as they engage in research in field settings. Consequently, Trevor and Kathy's poster discussion of inscriptions reflected the discourse around the collected data with which they participated during the field research itself. During their fieldwork, neither teacher developed an orientation towards referring to graphs and data tables in the posters, such as occurred in the recordings of conference presentations by scientists, because they had experienced no such enculturation towards those practices in their field research experience.

Overall, one could characterize these sorts of general statements of findings as being ones that represent qualitative as opposed to quantitative relational comparisons between phenomena observed in the field research. This difference is, we suspect, significant, as it characterizes the difference between how one engages in understanding phenomena in one's own everyday life and the detailed types of distinctions necessary to construct more explanatory scientific models. In the former case, a qualitative understanding of relations between observed phenomena is both sufficient for and consistent with practices we engage with and understandings we have of phenomena on an everyday "in-real-life" basis. However, to construct and test the broad, conceptual, formulaic mathematical models that are the penultimate goal of scientific research, one must learn to understand the relations of phenomena in substantially greater detail with more nuance. Thus, those becoming specifically enculturated towards full participation as researchers are encouraged, in their professional settings such as conferences, to discuss data relations in a manner that allows one to achieve the development of science theory, which explains the quantitative foundations of those academic discussions.

So, in our view, the teachers in this study participated with and effectively appropriated practices and discourse that represented that which was present in the field settings in which they worked but not those discursive and rhetorical practices present at conferences or in publications of formalized science findings that are embedded in theoretical and conceptual frameworks. This suggests that developing approaches to further teacher participation in these practices (such as developing understanding of argumentation reported on by Chowning [110]) may be beneficial, while recognizing that there are issues with participating with fieldwork (see [111]) that may need to be addressed for some teachers who are interested in such activities. Other approaches taken during an RET may also be productive in expanding teacher understanding of how to talk about research. For instance, scientists working with teachers in an RET could model how they present their research at a conference, highlighting how they use graphs and data tables to support their arguments and claims. It is possible, for instance, that Trevor and Kathy could have better incorporated graphs and tables in their discussions of the posters but did not do so because they did not realize it was a core practice of science presentations in scientists' CoP. Field RET activities could also balance data collection engagement with some in-field data analysis and claim-making activities (although we note that this might be asking the scientists to misrepresent their field research practices and thus be less "authentic") as an approach to developing teacher data literacy practices.

The implications of this are important for developing future participations in real-world science if one wants to develop teacher competencies that better reflect the evidence used to construct science claims (i.e., improved data and graph interpretation skills). Participating in fieldwork such as these teachers did appears to have generated competency in a considerable number of scientific practices (material, discursive, rhetorical, etc.), although apparently less so in the detailed discussion of the relations between phenomena or in the everyday use of inscriptions in understanding these relations. We conclude that for RET activities, an increased participation in after-field-season types of analytic activities in which teachers are part of the sense-making data practices of scientists may be an important component in teachers' appropriating further competency at the abstracted theorization component of scientific practice.

This is not to say that participation in field settings at this study's level was unproductive for teaching practices. As "teacher scientists," both participants in this project reported that their involvement influenced their teaching about and use of inquiry, that it positively affected their self-efficacy, and that their telling of firsthand "Stories of Me" about working in research gained them more credibility in science with their students. Field experiences such as those these teachers engaged in also broaden opportunities for teaching science. As Ford [81] notes, even using the stories of others, such as by using trade books in elementary classrooms, is "not likely to convey a sophisticated image of the nature of science without contextualization by teachers and other knowledgeable adults" (p. 214), and these field experiences provide that type of context for using those types of stories.

Finally, we acknowledge that this qualitative study focused on two teachers who may not be representative of a broader selection of teachers who could participate in RETs and further that how the group of teachers was chosen to participate in the LTER RET over four seasons may be subject to an unknown selection bias. As such, even though we believe our two volunteers were representative of outcomes for the overall group at the LTER field site (based on engagement with them over multiple field seasons), our findings may only reflect the competencies of the two teachers we interviewed in this study.

Author contributions: Conceptualization, GMB and PH; methodology, GMB and PH; formal analysis, GMB and PH; investigation, GMB and PH; resources, GMB and PH; data curation, GMB and PH; writing—original draft preparation, GMB and PH; writing—review and editing, GMB; visualization, GMB; project administration, PH; funding acquisition, PH. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: This work was supported in part by grants to Patricia Hembree from the Georgia Teacher Quality Higher Education Program and from the NSF through the LTER School Supplement Grant. This study was approved by the Institutional Review Board of the University of Georgia and the Research Ethics Board at the University of New Brunswick.

Institutional review board statement: This study was approved by the Institutional Review Board of the University of Georgia and the Research Ethics Board at the University of New Brunswick.

Informed consent statement: Informed consent was obtained from all subjects involved in the study.

Conflict of interest: The authors declare no conflict of interest.

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