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Science Projects: Indicators of Teachers' Feedback on Use of Graphical Inscriptions

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Abstract

What students learn about science and science practice can be inferred by examining student work about science other than their class work. There are two components to this study. The first is a broad examination of projects participating in a national science fair over several years to ascertain what types of inscriptions (from which orders of variables can be inferred) are used in their projects. This data is compared to patterns of inscriptional use at professional science conferences. The second component is a detailed examination of six specific randomly-selected projects to gain insights about use of inscriptions by students in their presentations. Results suggest that there are broad-based (considering the data source) issue with how data representation/graphing is taught in schools, and that teacher education programs need to specifically focus on this issue so that student teachers are better prepared to deal with these issues.

Key words: science, project, feedback, graphical inscriptions, teacher education

Introduction

Apart from standardized tests, there is generally little opportunity to examine student science work outside of regular school work, especially in broad samples that represent more than just the local school community and curriculum. Yet, such broad samples are necessary to understand how systemic problems with curricular areas such as student use of inscriptions may be. To better understand these issues on a country-wide basis, the author has been conducting research at the national science fair for several years. This venue offers the researcher the opportunity to (a) examine in detail presentations of student inquiry work from across the country, (b) discuss this work with students, and (c) examine use of inscriptions in these projects.

Graphs are a central component of the conduct of science and the conclusions drawn from research work (Latour, 2007; Roth 2003). This would suggest that graphical literacy should

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therefore be an important component of science literacy for children. Reform documents in the United States do suggest that data literacy, including that involving graph use in the context of representations of data collected in laboratory investigations, should be part of science literacy for children (AAAS, 2003; NRC, 2006; NSB,2009; NSF, 2006). Although there are numerous studies suggesting that there are various issues with student-teachers engaging in conducting inquiry investigations (Bowen & Bencze, 2008; Bowen & Roth, 2005) and interpreting data (Bowen & Bartley, 2007; Roth, McGinn, & Bowen, 2008), there appears to be little research on whether these issues persist with practicing teacher. However, doing such research, especially directly, is rife with difficulty. Such research is nonetheless necessary in order to understand whether the issues with inscriptions that have been identified in populations of student teachers continue to persist in practicing teachers, or if they are resolved through teaching experience.

Science fairs are perhaps the most common experience students have with conducting independent inquiry investigations. Science fairs are ubiquitous in school systems across North America. School systems in most states and provinces hold science fairs, and students are often required to participate in them. These projects usually progress through at least a school science fair and a regional science fair before being selected for the national science fair (some projects also go through sub-regional fairs before advancing to regional science fairs). It is only after successfully progressing through these competitions that a student project reaches the national level. Thus, before they reach the national science fair, student project (and the presentations students conduct about the projects) have been viewed and commented upon by the public, judges (who are often teachers), and by the classroom teachers, and at the national level can be considered to be "polished" in that they have both been subject to extensive feedback and critique, given the previous judging, represent the best science investigation projects conducted by students in the country.

Science Fairs and Inquiry in Schools

In varying degrees, "authentic" science inquiry tasks are promoted for schools in most curriculum and reform documents (AAAS, 2003; NRC, 2006; NSB, 2009; NSF, 2006).

Although there are many definitions of "authentic" inquiry tasks (Chinn & Malhotra, 2002; Roth 2005), in general they involve asking a question with a (more-or-less) unknown answer, developing a defensible methodology to address that question, collecting data which addresses that question, analyzing the data using approaches which are generally acceptable to science communities (generally involving summarization in tables, use of graphs, and the use of statistics), and drawing conclusions and implications from the findings (most often by embedding them in what is already understood). Generally, this describes the types of projects and activities engaged in by students for their science fair projects. One can argue that science fair projects and their presentation are a reasonable analogue of the conference presentations made by scientists. Thus, it is not unreasonable to ask to what degree science fair participants, whose projects represent the elite projects produced across the country, use the rhetorical strategies (both verbal/written and inscriptional) commonly engaged in by scientists in their own conference presentations.

Despite the prevalence of student participation in science fairs, there is surprisingly little published research on science fairs or student participation in them. This is significant because science fairs provide an opportunity for students to learn (a) to "do science" by engaging in inquiry as opposed to just learning about the products of science, and (b) "about science" (Hodson, 2003; NRC, 2000, p. xv), which is what much of school science stemming emphasize (Chinn & Malhotra, 2002; Desautels, Fleury, & Garrison, 2002; Eisenhart, Finkel, & Marion, 1996). Thus, understanding the learning about science that is demonstrated by students at science fairs provides the opportunity to understand the learning of "top" science student as they progress along the trajectory from newcomer towards being a scientist (Lave & Wenger, 2001) and their work ultimately demonstrates the practices they have learned about, including in their school science classes. Thus, this work likely reflects what students have learned in school about doing, and reporting on, science investigations. Given that these are "elite" students presenting winning project at the CWSF, and the parallel between this activity and the conferences at which scientists present their research, the researcher felt that a discussion of the role of science conference was warranted.

Communication of Findings in Science – The Role of Conferences

Science represents an "Epistemic Culture" such that, within any science discipline, knowledge "grows" through both formal and informal mechanisms. Although there are arguably differences between the specific functioning of this epidemic culture in different science disciplines (Knorr-Cetina, 2009), there are also many fundamental similarities that are taken to characterize science as a broad discipline of inquiry. For instance, in most disciplines findings are often discussed as they emerge, often before any formal analysis occurs, within the research group involved in the study. This discussion can happen both 'locally' within a particular laboratory, more broadly between laboratories (such as at departmental seminars within a university), and at conference as stories are told and swapped back and forth within both the formal and informal settings (Bowen & Roth, 2002a). Often, this knowledge, both procedural and conceptual, is tacit as it emerges in informal discussion through personal contact (Collins, 2010).

Ultimately, science research is written about with the purpose of constructing compelling and convincing arguments about the reason for, and import of, the data which is presented. In research papers, this is done by compiling a collection of evidence (called data) which is presented using written rhetoric, combined with a presentation of the data in various inscriptions (such as tables and graphs) and other convincing evidence (such as photographs, diagrams and models), to lead the reader to deem as acceptable the data collection methodologies, the analyses, and the final conclusions proffered by the researcher. Apart from the evidence itself and its analysis, just how convincing and compelling the arguments are taken to be also resides in how the preceding are embedded in the findings and writings of other authors. Ultimately, whether one's findings from a piece of rescue are in and of themselves accurate and relevant is not the sole determinant of acceptance (both within the community and for publication), as science "knowledge" – acceptance also relies both on how well the findings are "packaged" using the various inscriptional tools and on its embeddedness within those other studies.

Academic conferences represent a "middle step" in the development of final knowledge claims from research, as it is through participation in conferences that scientists get to "test" the convincingness of their studies, analyses, and conclusions. In conference settings, scientists report on both work "in progress" as well as studies that are completed (or, more appropriately, ready for public presentation and defense and, ultimately, publication). Sociological studies of science practice argue that inscriptions such as graphs and tables are central to these rhetorical practices of science (Latour, 2007; Lynch, 2005), and this is further evidenced by their prevalence in science publications where instructional use focuses on the use of higher order inscriptions (i.e., scatterplots and equations) rather than lower order inscriptions (i.e., photographs, drawings, and bar charts; Roth, Bowen, & McGinn, 2009). Thus, in this paper, the researcher takes the perspective that the use of graphs and tables in ways which parallel their use in the community of scientists, particularly in their usage in writing and in presentations and the complexity of the inscriptions, is an important indication of literacy in the argumentation practices of science.

This study specifically examines student projects to understand (1) the use of inscriptions by students in reporting their findings from their science fair projects and (2) whether the inscriptions used at science fairs are a reasonable representation of those used in science itself with the purpose of providing insights into the instructional practices and inquiry that students experience in schools under the guidance of their science teachers.

Research Methods

For this study, the researcher draws on information from several sources. First, the researcher analyzed data representing the use of inscriptions and argumentations by students in the Science Fair and contrasted it with the use of inscriptions by scientists (researchers and graduate students) in poster and slide presentations given at professional conferences.

Over 5 years of attending the Science Fair, various types of data have been collected for each year depending on what research permissions were granted that year, what information was provided by the Science Fair organizers, and what information was available from the Science Fair websites. These data types include interviews with students, provided organizer materials (e.g., a judging guide, benefits to sponsors information, schedules for the fairs, etc), photographs of exhibits (taken by various Science Fair organizers on their websites), video of students discussing their exhibit, videos and photographs of awards ceremonials Science Fair newsletters/bulletins, and ethnographic field notes. For this paper, the researcher has focused on photographic data resources available from the 2007, 2008, and 2009 North America-wide Science Fair because for those years the researcher had the most detailed and comprehensive information on student project presentations. Specifically, in this paper the researcher conducts an analysis of (1) detailed high-resolution photographs of five life sciences projects assigned to one group of middle-level judges at a recent Science Fair (from whom comments about the projects were elicited from some judging members) as well as photographs of one of the top winning projects in the "junior" category (taken during public viewing hours), and (2) photographs of 100+ exhibits made available on-line by the national science fair committees (focusing on 2 years when the local committees sponsoring time North America-Wide Science Fair provided numerous photographs on-line which were amenable to analysis). Projects in the latter category were done on projects drawn from the Science Fair categories of biotechnology, environmental studies, engineering, life sciences, and physics at the middle and high school level, and analyses of these project photographs focused on the use of inscriptions and statistics in 20 student summary reports from one of those years.

To provide a grounded comparison for the discursive and inscriptional resources of the science fair participants in their discussions/presentations of their projects, data were collected on poster representations of research work by university scientists as presented at formal academic conferences. Detailed photographs of conference posters were collected at three university institutions, focusing on the life science area. The analysis of these posters focused on enumerating the frequency of different types of inscriptions used to help construct the arguments in the posters.

The analyses of the posters, videotapes, and transcripts of interviews were based on interaction analysis (Jordan & Henderson, 2005) and drew on grounded theory (Strauss &

Corbin, 2000). In examining and analyzing the data set, the researcher first independently viewed transcripts, video, field notes, the text of web-based discussions, and other materials, and constructed assertions from them. Then, in joint sessions, the researcher examined these assertions, critiqued each perspective, and examined the database for confirming or disconcerting evidence. Final claims arose from such iterations.

Research Findings

Overall, there were considerable differences between the poster presentations of the students at the North America-Wide Science Fair and those typical of science presentations. These differences included how the projects were referred to, how data was represented, and the complexity of the data that was represented. The difference is particularly noteworthy given that the student projects being analyzed represent the work of the top science student in North America, and as such arguably represent the ultimate scaffolding in the school system of students towards science literacy. The researcher will present the findings of the analysis of student project titles, the use of inscriptions in student reports, the use of inscriptions in student poster presentations, and finally, a discussion of the content of the six posters.

Description of Projects - Project Titles

Titles used in science publications typically describe the relationship(s) being studied in the research and generally refer specifically to the variables under study and the relationships between those variables. In contrast to titles typical of science research presentations at professional conference, project titles used by the students at the science fair were frequently non-descriptive of the studies they were conducting, referring neither to the variables or organisms being studied nor to the relationships being examined. For instance, student projects were given titles such as "Go Goat, Grow", "Just Cloning Around", "Grapefruit Alert", "Don't Bug Me", "Team Phyto", "Go Green", "Have you been Juiced Today?", "Hanging by a Thread", "Nature's Secret Dimensions", "Soak it Up", and so forth. In the analysis of student reports/projects, only a minority of the titles of student projects at the Science Fair (15 of 135) reflected the sort of descriptive titles present in typical science publications. Thus, the researcher concluded that students do not generally engage in canonical science practices when titling their study for presentation.

Use of Inscriptions in Project Reports - Type of Inscriptions

Apart from their poster presentation at the conferences, students were also responsible for submitting a "report" to the Science Fair judging committee prior to their attendance. In the examination of these reports, the researcher found that a total of 94 out of 135 Science Fair project reports used inscriptions such as graphs (47 projects), tables (36 project), and images (illustrations or photographs; 45 projects). There was a split in the depiction of lower-order relationships (bar & pie charts: total of 30 projects) and higher-order relationships (scatterplots & formula: 22 & 4 projects respectively). What is most evident is that the student summary reports (reports submitted to the judging committee) infrequently used inscription, particularly graphs and tables, as part of describing their projects and findings.

Science writing is typified by the use of descriptions of inscriptions in the body of the text so that the reader is brought to a clear understanding of the intent of the author in including the inscription (Roth, Bowel & McGinn, 2009). Project reports were examined to determine the embeddedness of the inscription in the text of the report.

Proportion of Reports with Different Types of Inscriptions

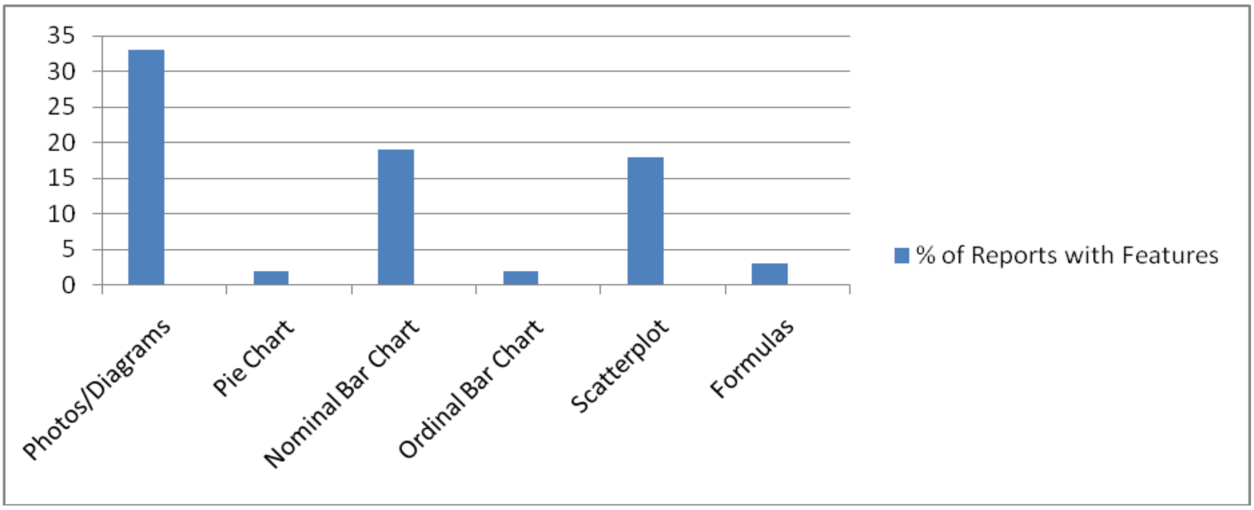

Figure 1: Use of Inscriptions in Project Reports – Integration of Inscriptions into Text

Three categories were used: (1) "no reference" to the inscription or its contents, (2) "implied reference" to the inscription (the inscription/contents is referred to but not directly, thereby requiring the reader to draw the connection between the statement and the inscription), and (3) "direct reference" to the inscription (where the author directly refers the reader to specific parts of the inscription). Of the 88 reports with inscriptions which were analyzed (six of those with inscriptions were excluded as they were in French, in which the researcher is not fluent), 21 of them did not use any reference to the inscriptions whatsoever. Thirty of the reports had a direct reference in the text to the included inscriptions and 37 made an implied reference in the text to the inscription. Overall, this means that of the 129 reports for which it was possible for the researcher to analyze, slightly 'under one-quarter of them (30) engaged in canonical science writing practices, at least as far as the use of inscriptions and their embeddedness in text is concerned.

Use of Inscriptions on Posters - Comparing Science Fair Posters to Scientists' Posters

In general, student posters tended to use more lower-order inscriptions (i.e., pie and bar charts) and fewer higher-order inscriptions (i.e., line charts, scatterplots, and data models) to represent their project day that scientists did. This suggests that student projects tended to focus more on nominal and ordinal level comparisons, rather than the interval-ratio correlational data more common in published science research (Roth, Bowel, & McGinn, 2009). In addition, student posters had a higher frequency of the use of photographs than did posters by scientists.

Proportion of Posters with Different Inscriptions

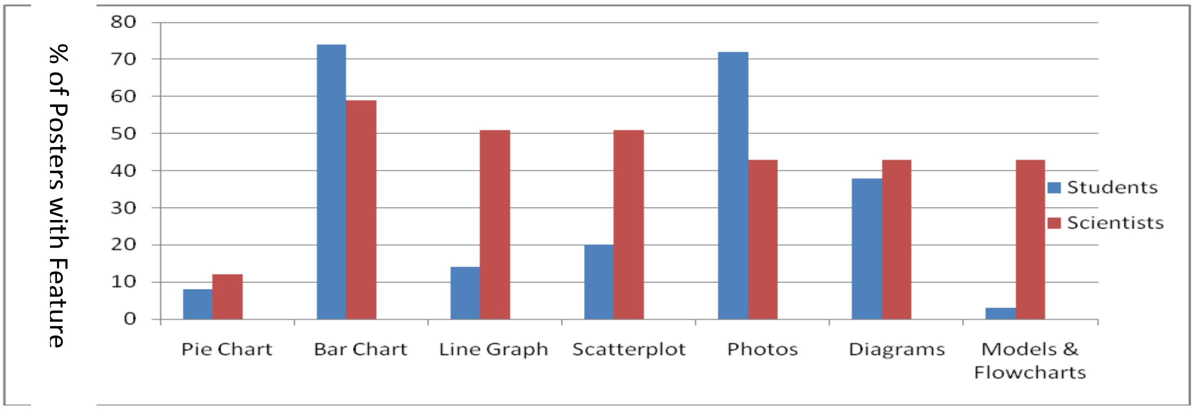

Figure 2: A Comparison of the Use of Different Types of Inscriptions on Scientists' and CWSF Posters

In a comparison of only those student posters that did use inscriptions, frequency of the use of the different types of inscriptions again varied between the scientists and the students on those posters. On average, posters by scientist used higher order inscriptions more frequently than did the student posters. Student posters focused more on use of lower order inscriptions (4 bar charts and 3 scatterplots per poster on average) than did those by the scientists (3 bar charts and 18 scatterplots per poster on average). This suggests that student projects were more likely to investigate questions comparing categories (e.g., Soap A compared to Soap B), than co-varying interval-ratio investigations (such as cleaning effectiveness at different temperature).

Detailed Examination of Inscription Use

A detailed analysis of the five exemplar science fair projects assigned to one judging team (therefore representing a random selection) suggests that there are pervasive issues with the use of inscription in science fair projects (Table 1). Apart from the one project that did not collect quantitative data, the four other projects all had issues with their use of inscriptions. [Ironically, despite an ordered qualitative approach to representing the data in the non-quantitative study (from which patterns were abundantly evident), the project was viewed negatively by many of the judges.] Issues ranged from minor (such as labeling which was inadequate for understanding the graph without reading text panels on the poster) to more serious issues such that interval-ratio data were depicted in bar graphs instead of scatter-plots thereby distorting the overall visual patterns and confounding interpretation with respect to the original statement of problem. Apart from graphical issues, other problems were also apparent. For instance, one project (Junior Project 5) attempted to test for statistical significance using a simple ANOVA test. However, the test was done incorrectly, both violating necessary assumptions of the test as well as being conducted on inappropriate data for the conclusions which were drawn (problems which, notably, were also not noticed by most of the judges).

Table 1: Summary of Projects Assigned to One Judging Team (Junior Life Science Category)

Project Level	Independent Variable	Dependent Variable	Type of Graph	Table	Dependent Variable Patterns Easily Discernable	Other Issues
Junior						
Project 1	Interval-Ratio	Interval-Ratio	Bar Chart*	No	Yes	
Project 2+	Interval-Ratio	Interval-Ratio	Scatterplot	No	No	Abscissa & Ordinate Reversed
Project 3	Nominal	Interval-Ratio	Bar Chart	No	Yes	Inadequate titles confounded interpreting graphs
Project 4+	Nominal/Interval Ratio	Interval-Ratio (not measured)	None (Pictorial Table)	Yes	Yes	
Project 5+	Interval-Ratio	Interval-Ratio	Line Chart*	Yes	No	Multiple graphs needed means and combining
Intermediate						
Project 1+	Nominal/ Interval-Ratio	Interval-Ratio	Bar Chart*	No	No	
+ Award winning project *Indicates that graph type(s) chosen to depict data is non-canonical						

Discussion and Implications of Findings

Data as represented are foundational to describing data patterns and the subsequent explanations as to why those patterns occurred. The trajectory of making observations to modeling those observations in an explanatory frameworks which generally characterizes the practices of science, more often than not involves studies which depict (multiple) co-varying interval-ratio data. Thus, competency with the appropriate use of inscriptions is a cornerstone to understanding and making sense of the world.

The researcher chose to examine projects of Grade 8 student and a Grade 10 student because the work within those projects should easily fall within the competence of science teachers both with respect to the content and the representations of data that result from the research projects. This paper, which examined the science projects of many of the top science students in North America, suggests that there are issue with respect to the use of graphs in school science and what students are taught about their use.

One can view the students in their use of inscriptions as having progressed somewhat along the trajectory towards canonical science practices with their research work. However, previous research suggests that in an appropriate educational setting, students (and not just the top students) can gain considerable facility with projects that involve co-varying relationships of interval-ratio variables (Roth & Bowen, 2004). Why might so little of this type of work be evident in the science fair projects of the elite North American science students? Overall, less than a quarter of the studied projects demonstrated data that suggested that students were engaged in the correlational type of research that typifies science. Not only do their studies generally represent the use of lower order variables (nominal-level studies), the titles they use also suggest that students are not taught to think of investigations as being intended to examine the world from the perspective of relational concepts for which the world represents concrete examples, but from an exemplar perspective only. Rather that referring to a study as "An investigation into factors affecting environmental pollutants in car exhaust," the study was titled "The deadly cost of car exhaust" even though the former clearly better describes the investigation and data outcomes of the study. Interviews with students also suggests this, as often their rationale for investigating a problem is one of local or personal interest, but one which the reports do not suggest much of a use of science theory extends into.

Previous research suggests that in an appropriate educational setting, students (and not just the top students) can gain considerable facility with projects that evolve co-varying relationships of interval-ratio variables (Roth & Bowen, 2004). Yet, in this study the researcher can see that although students use graphical inscriptions with a frequency approaching that of those found in science reports themselves, and thus can be said to have appropriated the representational intentions of practiced science, their inscriptions tend to focus on lower-order graphs with less (or no) explanatory power. The data analysis of the "junior" level projects suggests that they frequently chose interval-ratio (IR) variables for their studies but did not depict their findings in graphs/formula typically used with IR data (scatterplots or mathematical models). Again, the researcher reiterates that this commentary might seem overly critical; however, these students do not represent those of an average classroom, but rather are the "best" students and projects in the country and thus such higher-order representations are well within the competency range of these students.

Ongoing research engaging pre-service secondary science teachers, those who will be the teachers most responsible for encouraging students to work on science fair projects, in inquiry project work suggests that the teachers themselves have difficulty designing and conducting inquiry studies, and especially those involving co-varying variables (Bowen & Bencze, 2008; Bowen & Roth, 2005; Crawford et al., 2005). Studies of textbooks find that the use of inscriptions in those textbooks poorly mirrors their use in science itself. Not only do textbooks present a substantially higher number of lower-order inscriptions, they also embed them in the text in much less detail (Bowen & Roth, 2002b; Roth, Bowen, & McGinn, 2009); this reflects the issues with inscriptions the researcher reported here both in the reports and in the poster presentation by students. These findings deepen concerns regarding what students are learning in schools about the use of inscriptions both from their textbooks and from their teachers.

What is apparent is that two of the main influence on students in schools, their teachers and their textbooks, both present a use of inscriptions (and, therefore, implicitly, insights into the practices and questions of science) which are reasonably non-canonical, and that this appears to influence the type of research being done by students who are skilled enough to make it to the national science fair. Science teachers enact teaching practices which reflect the nature of their own understanding of the practices of a discipline (Bencze, Bowen, & Alsop, 2006). One might therefore speculate that it is the limitations of teachers with respect to instructional practices and experiential understanding of science practices that ultimately limit the types and complexities of projects worked on by students at the CWSF, and therefore ultimately all student in their own classes.

Apart from the issue involving the modeling of science by teachers and textbooks, there are also few opportunities for students to participate in collaborative communities of practice such as are often found in professional communities (Lave & Wenger, 2001; Wenger, 1998, 2000). Furthermore, despite the opportunities offered using the internet, none of the organizing bodies of science fairs provide any mechanisms (such as discussion forums, private massaging, etc.) that would encourage peer communication and critique about student projects - in fact it might be argued that this type of empowering of students might be antithetical to their interests (Bencze & Bowen, 2005). Overall, science fairs appear to model and encourage a version of science inquiry which is both competitive and individualistic with little opportunity for ongoing collaboration within a community of peers.

Until these issues are addressed, it appears there will be little opportunity for a broader science literacy and competency with science to emerge. The researcher suggests that pre-service teaching programs at least: and probably also undergraduate science programs, would benefit from a course focusing on conducting inquiry investigations, orders of variables, representing data in tables, and also analyzing and presenting data in graphs. An informal review of seven pre-service secondary science methods textbooks (Bowen & Bartley, 2007) suggests that although data and graphing skills are considered important for students to learn, they are seemingly a skill which it is assumed individuals possess entering a faculty of education, as the textbooks in that review provided no resources about data and graphical transformation/analysis to develop understanding of these issues in the student teachers. Until the teachers themselves develop competency at conducting science inquiry investigation, analyzing and graphing data, and constructing claims in a canonical fashion, there will be little opportunity for their students to participate in projects which allow them to gain clear competency at those practices. Finally, the researcher wishes to make it clear that none of the analyses here is intended to be critical of the student participants or the science fair itself but rather the researcher wishes to thank both for the lens they offer into the practices that students are learning from their schooling which are reflected in the projects presented at the science fair. Students' participation in science fairs is thus contributing not only to their own growth in science, but also to research about what needs to be better addressed in schools themselves.

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