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The Structure of Scientific Arguments by Secondary Science Teachers: Comparison of Experimental and Historical Science Topics

Ron Gray and Nam-Hwa Kang

Oregon State University, Dept. of Science & Mathematics Education, Corvallis, OR 97331 USA

Abstract

Just as scientific knowledge is constructed using distinct modes of inquiry (e.g., experimental or historical), arguments constructed during science instruction may vary depending on the mode of inquiry underlying the topic. The purpose of this study was to examine whether and how secondary science teachers construct scientific arguments during instruction differently for topics that rely on experimental or historical modes of inquiry. Four experienced high school science teachers were observed daily during instructional units for both experimental and historical science topics. The main data sources include classroom observations and teacher interviews. The arguments were analyzed using Toulmin's argumentation pattern revealing specific patterns of arguments in teaching topics relying on these two modes of scientific inquiry. The teachers presented arguments to their students that were rather simple in structure but relatively authentic to the two different modes. The teachers used far more evidence in teaching topics based on historical inquiry than topics based on experimental inquiry. However, the differences were implicit in their teaching. Furthermore, their arguments did not portray the dynamic nature of science. Very few rebuttals or qualifiers were provided as the teachers were presenting their claims as if the data led straightforward to the claim. Implications for classroom practice and research are discussed.

As the world increasingly depends on science and technology, the goal of scientific literacy for all has become critical, and accordingly learning about science, i.e., the nature of science is essential (OECD, 2006). For the content of nature of science to be taught in schools science educators have generalized the perspectives from science studies including the philosophy, history, and sociology of science to a set of universal statements about science in an attempt to represent how science works (Abd-El-Khalick & Lederman, 2000; Matthews, 1994; McComas, 1998; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). The current U.S. science education reform document (National Research Council [NRC], 2011) describes science as a set of practices within which students will understand both scientific concepts and the development of those concepts. The practices include asking questions, developing and using models, constructing explanations, and engaging in argument from evidence to name a few. Similarly, the science curriculum in the UK identifies a set of practices such as ways of collecting and analyzing data and developing explanations using scientific theories, models and ideas (Department for Education England, 2007).

Recent developments in science studies have begun to call into question the prevalent general characterizations of science (Allchin, 2011; van Dijk, 2011; Ford, 2008; Rudolph, 2000). Our understandings of scientific practices are informed by science studies that have utilized, among others, ethnographic methods. Studies depict how scientists construct theories, negotiate claims, and interpret observations in various science fields such as organic chemistry (Myers, 2008; Bond-Robinson & Stucky, 2005), biology (Roth, 2009; Myers, 1990; Lynch, 1987), biochemistry (Knorr-Cetina, 1981), biomedical engineering (Nersessian, 2005; 2009), physics (Collins, 1992; Traweek, 1988), nanoscience (Ruivenkamp & Rip, 2010) and engineering (Osbeck, Nersessian, Malone, & Newstetter, 2011). The growing body of studies about scientific practices has revealed how different scientific communities engage in discourse and, in particular, argumentation practices differently. From a perspective of science as cultural practices, science is understood as a situated practice, dependent on the interactions of communities of researchers and historical circumstances within fields of study and even within individual research groups (Buchwald, 1995; Galison & Stump, 1996; Knorr-Cetina, 1999; Pickering, 1995a, 1995b; Rouse, 1996). Because scientific practices are epistemic activities in which knowledge is constructed, the differences in practices across various science fields or communities can be clearly noticed in the way arguments or justifications are made in constructing knowledge. General statements such as engaging in arguments based on evidence or developing explanations based on evidence fall short of describing science as heterogeneous practices.

It is neither possible to depict accurately how science works in its full complexity nor necessary. Ultimately, decisions need to be made about how to describe science in the curriculum and the selection of general statements about science to be taught in schools is shaped by the social political factors and entails consequences (Rudolph, 2003). What have been typically left out in the portrait of scientific practices are the fields of science that do not rely on experimental justification. These include historical sciences such as geology, evolutionary biology, and cosmology which developed different methodologies to cope with problems that cannot be solved experimentally. We believe what we highlight as scientific practices implies the others left out are less legitimate. At a minimum, therefore, two different modes of scientific inquiry, i.e., experimental and historical sciences, could be distinguished in teaching about scientific practices. The distinction of the two, described more fully below, will provide a meaningful start to distinguishing a variety of scientific inquiry methods utilized in various science fields and developing sophisticated knowledge about epistemic process in science which is critical to the development of scientific literacy.

The purpose of this study is to examine whether and how secondary science teachers construct scientific arguments during instruction differently for topics that rely on experimental or historical modes of inquiry. Specifically, this study seeks to answer the question: What structural differences in scientific arguments exist, if any, between scientific arguments constructed by secondary science teachers for experimental and historical science topics? While the distinction of the two modes of inquiry can be seen as oversimplifying the multiple modes of modern science inquiry, we believe it is a meaningful start to differentiate various epistemic practices adopted in sciences.

Defining Two Modes of Scientific Inquiry

Providing a reasonably authentic context for science learning requires a greater understanding of the actual methods of inquiry as practiced in diverse disciplines. Since the late 1970s, ethnographic studies have documented the activities in a variety of sciences. In addition, cognitive scientists have studied the cognitive process of science demonstrated in laboratory settings (Nersessian, 2009; Dunbar, 1995; Klahr & Dunbar, 1988; Neressian, 1992) and in scientific research artifacts (e.g., research notes and diaries) (Giere, 1988; Neressian, 1992). With few exceptions (e.g., Roth & Bowen, 2001) the vast majority of these studies have addressed experimental sciences such as physics and chemistry while leaving out historical sciences that utilize naturally occurring data as a primary source of evidence. It is our contention that such a concentration on experimental sciences leads to a mistaken impression that science disciplines in general operate in a similar way in terms of their methodologies and types of reasoning employed.

This lack of focus on sciences that do not rely on experimental methods has led philosophers of science (Brown, 2011; Cleland, 2002; Jeffares, 2009; Tucker, 2011; Turner, 2007) and scientists themselves (Diamond, 1997; Erwin, 2011; Gould, 1986; Mayr, 1985; Schumm, 1991) to more thoroughly examine the historical sciences. While the discussion over what truly separates these two modes of science continues, some areas of consensus have emerged. Diamond (1997) summarizes these features that set the two apart as methodology, the role of prediction, causation, and complexity.

Experimental sciences (e.g., chemistry, physics, molecular biology) ask questions in which direct experimentation is possible. Therefore, in these sciences, knowledge is constructed through controlled experiments in which natural phenomena are manipulated, often in order to test a model or theory (Table

1). For example, Ernest Rutherford's Geiger-Marsden experiment in which positively charged alpha particles were directed at a thin layer of gold foil tested the prevailing "plum pudding" model of the atom by revealing the existence of the atomic nucleus. Models or theories are evaluated on the consistency between predictions and experimental results as well as generalizability to a wide range of phenomena in multiple contexts. The goal of these experimental sciences is to find general laws or statements (e.g., kinetic molecular theory) that are made possible by the uniformity of the objects under study (e.g., atoms). In other words, these sciences concern natural events that are general and repeated easily.

[Insert Table 1 about here]

The historical sciences (e.g., paleontology, cosmology, evolutionary biology), on the other hand, gather evidence by observation because direct experimentation is usually impossible. These sciences utilize observational evidence in order to investigate ultimate causes from the past whose effects must be interpreted from complex causal chains of events (Mayr, 1985). For example, Alfred Wegener used multiple pieces of evidence (biogeography of extinct organisms, the complementary arrangement of continents, patterns in glacial sedimentation, etc.) to argue for the theory of continental drift. Thus, the quality of this research is often based on the adequacy of the explanation rather than successful prediction because it is based on the study of complex and unique entities (e.g., plate tectonics) that have a low probability of repeating exactly. In other words, these sciences attempt to construct causal explanations for unique events (often in the past) using multiple lines of evidence in lieu of direct experimentation. In addition, reasoning in historical sciences consists largely of explanatory or reconstructive reasoning (i.e., "retrodiction") compared to predictive reasoning from causes to effects in experimental sciences (Diamond, 1997; Gould, 1986). Retrodiction refers to inferring the past from the present as was done in the continental draft example.

It is important to note that, while the historical sciences are typically not experimental, historical scientists do conduct experiments. For example, experiments conducted in genetics and biochemistry have been instrumental in the development of evolutionary biology. However, what are thought of as the main principles of these sciences are broad historical claims that are not open to direct testing. Interestingly, Brown (2011) has recently made the case for ecology being included with the historical sciences. While ecology does not often involve explanation of past events, it does, according to Brown, share epistemological and explanatory characteristics with the traditional historical sciences.

Inquiries into the historical sciences have been taken up by science education scholars. For example, in his explanation for inquiry in the geological sciences, Ault (1998) points out that “geology is not physics” (p. 190) and claims that reasoning involved in explanations of geological phenomena relies on contingency and ambiguity in contrast to generalization in experimental sciences that aim for prediction. For example, chemists are able to generalize the gas laws based on experimental results and predict how gas reacts when pressure and temperature change. However, an explanation of earthquakes, for example, is to infer what has happened before to result in the current event. Thus, expert understanding in geology requires restricting the ambiguity inherent in inquiry about unique events and the goal is to reconstruct past geologic events and processes from observational data that cannot be recreated in a laboratory. The explanations produced through a historical mode of inquiry such as this are contingent and case-dependent and are justified by explanatory power as opposed to consistency with prediction. Similar explorations that reveal the features of inquiry that are distinct from experimental sciences have been conducted in evolutionary biology (Passmore & Stewart, 2002; Rudolph & Stewart, 1998) and genetics (Cartier & Stewart, 2000; Dodick & Orion, 2003), among others.

Of interest to this study are not the specific distinctions between these two modes of science, but rather examining whether and how these differences manifest in the classroom. One possible way to examine the differences would be examining the discourse practices involved in argumentation, i.e., reasoning and justification. A comparison of classroom arguments between experimental and historical science topics would illuminate the differences between the two modes of inquiry as enacted in the classroom.

Argumentation in Scientific Inquiry

Argumentation is “a verbal, social, and rational activity aimed at convincing a reasonable critic of the acceptability of a standpoint” (Grootendorst & van Emeren, 2003, p. 1) and scientific argumentation is “a special case when the dialog addresses the coordination of evidence and theory to advance an explanation, a model, a prediction or an evaluation (Duschl & Osborne, 2002, p. 55). Science is not simply the accumulation of facts about how the world is, but it involves the construction of models, theories, and explanations about how the world may be (Giere, 1988). These explanations are thus open to challenge (Popper, 1959) and are constructed through dispute, conflict, and argumentation rather than through general agreement (Kuhn, 1962; Latour, 1988). As Pera (1994) states, science should be transferred “from the kingdom of demonstration to the domain of argumentation” (p. 47). Scientific argumentation is central to science practice.

As there has been an emphasis on teaching for knowledge construction science education researchers have promoted opportunities for students to construct explanations and validate them through science inquiry activities (e.g., Driver, Newton & Osborne, 2000; Sampson, Grooms & Walker, 2011). In those studies, engaging in scientific argumentation has been a critical part in which students make claims and support them with evidence. In these activities, scientific arguments have been treated as if general across all topics or science fields. Given the centrality of argumentation to science practices and the diversity in scientific practices across science disciplines or communities, it is reasonable to expect some differences in argumentation between different fields of science and in particular between experimental and historical sciences.

Dodick, Argamon and Chase (2009) analyzed patterns of language used by scientists in 1,605 scientific articles from twelve experimental and historical journals. In language features they found distinctive methodological differences. For instance, experimental sciences use more predictive statements and binary judgment of what is possible or not. In contrast, historical sciences use a more nuanced comparison of levels of confidence in constructed explanations. There seems to be a clear connection between methodology and discourse patterns. From the perspective of Bakhtin's social languages (1986), the differences between different disciplines of science are expected. As discourse communities within disciplines evolve, their language, methodologies, and justifications for "what counts" in that discipline would become increasingly unique. Thus, differences in argumentation patterns between disciplines would be expected. For example, as explanations in historical sciences rely on the coordination of multiple pieces of evidence, we would expect claims in historical arguments to include far more references to warranted data than claims put forth in experimental sciences. Important to this study is the question of whether or not these differences exist and can be identified in the science classroom.

Studies have shown that classroom discourse is dominated by the teacher (Carlsen, 1997; Russell, 1983) and indicate that teachers play a critical role in conveying the image of science. Thus, it is critical to examine teacher argumentation patterns in order to understand how science inquiry is depicted in the classroom. This exploratory study marks an initial step in a research program to find a way to convey the diverse modes of scientific inquiry in the classroom.

Methods

Participants

For rich information, we recruited teachers with science research experience and those who had expert teacher status in the school district. A total of four teachers (Scott, Matt, Gabby, and Robert) volunteered for the study. They were currently teaching science at one of two public high schools within the same district in a mid-sized city in the Northwest United States. Scott and Matt teach science at West High School whereas Gabby and Robert teach at East High School. They taught from 8 to 24 years and had master's degrees and research experience in their subject matter. They have all been recognized for their teaching including Matt who was named the state's teacher of the year. All have led professional development and two had leadership roles in local and national science education organizations.

Research Setting

The two high schools are in a large district known for serving students of a large range of socioeconomic backgrounds and a large migrant Hispanic population. District-wide, 54% of students are identified as living in poverty, 37% identify as Hispanic, and 17% of students are identified as English Language Learners.

For the purpose of the study, two units that covered experimental and historical science topics were selected for observation. For the biology courses, units on DNA and evolution were chosen (Scott, Gabby, and Robert). For physical science courses, chemical bonding and formation of solar system were chosen (Matt). These topics were chosen because they represented one of the modes of inquiry and fit within the study timeframe. Scott, Gabby, and Robert, selected one class to be observed during both instructional units. Matt selected one class of chemistry and one of astronomy. These classes ranged in size between 20 and 30 students.

Data Collection and Analysis

The main data sources included classroom observations and interviews with the teachers. All the lessons of each unit were observed and videotaped. Before, during and after unit instruction the teachers were interviewed for their instructional goals and plans. All interviews were audio recorded. All video and audio data were transcribed verbatim for analysis. Instructional materials used during observed lessons were also collected for analysis.

The data was analyzed through three concurrent processes: data reduction, data display, and conclusion drawing/verification (Miles & Huberman, 1994). Data reduction included transcribing, selecting, simplifying, and transforming the classroom observations and collected documents. After transcription, the first data reduction was to "fracture" (Strauss, 1987, p. 29) the transcripts to identify claims and relevant components. The fractured texts were reorganized into the claim categories. In the data display process, visual matrices were used to compare arguments from different instructional units (see Table 2 for examples).

[Insert table 2 about here]

While multiple analytic frameworks for argumentation exist (Sampson & Clark, 2006), Toulmin's (1958) argument model was adopted for the analysis because it allows for examination of the relationship between evidence and claims, the main frame of scientific arguments. The model describes argument construction primarily as a process of using data and warrants to convince others of the validity of a claim. He suggests six components of an argument: claim, data, warrant, backing, rebuttal, and qualifier. A claim is an assertion put forward publicly for general acceptance. To support a claim, data can be used. Data refers to facts or information that provide support for a claim. Statements that link data to a claim are called warrants. These warrants provide the reason why the data is evidence for the claim. Backings are generalizations that establish the trustworthiness of the warrant. A claim and data make up a simple argument while warrants and backings make it stronger by explicitly stating the logical connection between the claim and data. As for 'scientific' arguments, a claim, data and warrant would make a basic form of a scientific argument. In more complex arguments, rebuttals and qualifiers can also be used. Rebuttals refer to the circumstances that might undermine the force of supporting arguments. Qualifiers, on the other hand, are phrases that show the limitation of the conclusions or claims. Accordingly, these two elements make an argument sophisticated and complex.

The use of Toulmin's argument model required identification of teachers' statements that counted as parts of a scientific argument. We defined a scientific argument as those arguments that had a scientific knowledge claim accepted in the sciences. This focus on scientific arguments then disregarded purely persuasive arguments that are commonly used for the purpose of communication of ideas. These aspects of the teachers' arguments were examined elsewhere (Author, 2009). For example, an argument that had a claim that DNA is shaped like a double helix (a scientific description used in Watson and Crick's original article) was included in the analysis as a part of scientific argument while an argument that had a claim that DNA is "just a ladder, a twisted ladder" (an analogy used for rhetorical purposes in visualizing a concept) was excluded in the analysis. Once scientific argument statements were identified, all parts of them were then coded as a claim, data, warrant, qualifier, or rebuttal which were used to identify an argument's structure. The number of components linked to a claim provided further data on the complexity of the argument. As indicated in other studies (e.g., Duschl & Osborne, 2002), we found the differentiation between warrants and backings ambiguous. Thus backings were not included in this analysis.

It is important to note what Osborne and Patterson (2011) refer to as the "emergent confusion" in the science education literature of the terms explanation and argumentation. While there is overlap between the function of explanations and arguments, they differ in their epistemic functions. The purpose of an explanation is to provide a causal account of a scientific phenomenon whereas the purpose of an argument is to justify a claim to knowledge or to persuade. In this study, we view teachers' instructional statements made over days of lessons on a unit as arguments because unlike a textbook, teachers' discourse during lessons is more than one long causal explanation, but is an act of persuasion for a disciplinary idea (Alexander, Fives, Buehl & Mulhern, 2002).

Unit of Analysis

We argue that our study is distinct from other studies about scientific arguments in schools in terms of the unit of analysis. Data was collected and analyzed at the level of the instructional unit. Previous studies utilized Toulmin's argumentation framework at the level of small sections of discourse (e.g., Jimenez-Aleixandre, Rodriguez, & Duschl, 2000) or at an individual class session (e.g., Erduran, Simon, & Osborne, 2004). The analysis at the level of the instructional unit in this study examined argumentation across multiple lessons within a unit. In other words, we examined how a claim made in a lesson was revisited later in different lessons and supported multiple times. In so doing, we intended to understand how a science teacher developed a scientific argument over multiple lessons, which commonly occurs in teaching.

Trustworthiness

Member checks, triangulation, and inter-coder reliability were the main tools for ensuring the credibility of this study. For member checks (Lincoln & Guba, 1985) a semi-structured interview was conducted with each participant after the initial phase of analysis. During the interview the initial analysis of argument structures was presented and the teachers were asked to provide feedback on the analysis in terms of their lesson plans and enactments of them.

Triangulation of data sources and multiple researchers (Merriam, 2002; Patton, 1990) were also utilized. Data from the classroom observation and teacher interviews were cross-examined. Also, two researchers independently coded teacher arguments. Independent coding resulted in 92% consistency. The researchers discussed and resolved the discrepancies for the final analysis.

Results

In this section we present the comparison of the manner in which scientific data is used and warranted in the construction of scientific claims during instruction on experimental and historical topics. In this paper, we focused on the arguments in which a scientific claim was made although other persuasive statements were used during these units. Therefore, the results presented below represent only parts of the teachers' instructional discourse around these topics. An analysis of the teachers' persuasive arguments is presented elsewhere (Author, 2009).

Experimental science unit

For their experimental science topic, a unit on the structure and function of DNA in biology and a unit on chemical bonding in physical science were observed. What these topics share is a justification based on methodologies that rely on the manipulation of nature through experimentation. The teachers taught these units over three to eight 90-minute lessons.

The arguments constructed during the experimental science units showed a range in the number of scientific claims made. Not all of the claims were, however, supported by data (Table 3). For instance, Gabby's unit consisted of four scientific claims: DNA is shaped like a double-helix, DNA is contained in the nucleus of the cell, proteins regulate the chemistry in the human body, and DNA is common to all organisms. Three of these were supported by data. Matt's unit on chemical bonding, on the other hand, consisted of 14 scientific claims such as "the structure of the atom is due to physical laws" and "electrons are like waves and have spin." In Matt's case, only 4 of the 14 claims were supported with scientific data. Among a total of 30 scientific clams made by the teachers only 15 were explicitly supported by data.

[Insert Table 3 about here]

To be complete arguments, based on Toulmin's argumentation pattern, data statements must be explicitly linked with the claim through warrants. While not all claims were supported by data, those that were supported were warranted to result in basic argument forms (Table 3). For example, Gabby's claim about the DNA structure was supported by the data involving Franklin's x-ray crystallography photograph and warranted by a statement, "…this shape told Maurice, Rosaline, and James… that DNA was a spiral." Thus, the outline of the scientific argument was that DNA is shaped like a double helix [claim] supported by the x-ray crystallography [data] that showed a spiral shape [warrant]. Similarly, Robert's claim that DNA is in all living organisms was evidenced by a DNA extraction lab conducted by the students. This data was warranted by Robert displaying multiple organisms. Thus, the outline of the scientific argument was that all living organisms have DNA [claim] supported by DNA extraction [data] from one of many exemplary organisms displayed [warrant]. These scientific arguments made during units on experimental topics, however, did not include qualifiers and rebuttals (Table 3).

In short, in the experimental topic units, the teachers provided multiple scientific claims, but they were not always accompanied by scientific data. These scientific claims that are void of data would be what Schwab (1962) called a "rhetoric of conclusions" representing science as collection of facts. When scientific claims were accompanied by data, however, the data was warranted to the claim in nearly every instance revealing the scientific reasoning behind claims. On the other hand, qualifiers and rebuttals were never used. This lack of qualifiers and rebuttals in the scientific arguments constructed by the teachers portrayed the epistemic process of science as if a piece of data led straightforward to the claim.

Historical science unit

For historical science topics, the three biology teachers (Scott, Gabby, and Robert) were all observed during their unit on evolution. The physical science teacher participant, Matt, was observed in an astronomy class during a unit on the formation of the solar system. What the topics of these two units share is a justification based not on experimentation, but on observational evidence used to investigate the causes of past events.

Similar to the experimental science units, the arguments made during the four historical science units showed a range in the number of claims used. For instance, Gabby's unit consisted of 7 scientific claims whereas Scott's unit consisted of 16 claims (Table 4). These included such claims as "natural selection explains how things change to adapt to local conditions", "all species are variable in their characteristics", and "characteristics exist for a reason and because organisms have these traits that make them well suited to the environment tend to be successful." Unlike in the experimental science units, almost all scientific claims were supported with data in the historical science units. Among 42 scientific claims 41 were supported by data. In addition, the number of data statements used as evidence for each claim was much higher during the historical science units as compared to those of the experimental science units. The four participants used on average four pieces of scientific data to support each claim (Table 4). For example, during his evolution unit, Scott claimed that "all species are variable in their characteristics" and as scientific data he showed the variability in hand length and peanut size using a measurement activity as well as the variation in size of the people in the classroom.

[Insert Table 4 about here]

When data were used to support claims, almost all of the data statements were closely linked to the claim through warrants. In doing so, almost all claims were made in the basic form of a scientific argument. For example, in the case of the variation of hand and peanut length activity, Scott warranted, "If you graph it… every time you graph any measured variability you get this bell curve." Thus, the scientific claim that all species are variable in their characteristics was supported by two examples of variations [data] that were shown to have bell curves [warrant]. For the claim that biological changes in one species are often linked to changes in another (i.e., coevolution), one piece of data Gabby used was the relationship between leaf-cutter ants and fungi. She warranted this data to the claim, "the lives of the partners are so intertwined that when a biological change happens in one of them, it is accompanied by a change in the other." Thus, the claim about coevolution was supported by an example that showed change in one species (leaf-cutter ants) are intertwined with the changes in the other (fungi) [data] which is a common evolutionary relationship [warrant].

Similar to the experimental unit lessons, few arguments during the historical topics unit had qualifiers and rebuttals. The one exception to this was Scott who used three rebuttals during an in-depth coverage of historical hypotheses of solar system formation. For example, in discussions of the nebular hypothesis of solar system formation, he elaborated a rebuttal of its inability to explain the Sun's relative lack of angular momentum and how it was resolved: "the sun is rotating slowly so the majority of the angular momentum is held by the outer planets." Thus Scott presented the hypothesis along with evidence for (data) and against (rebuttal) it that occurred in the process of accepting the hypothesis. In so doing, scientific practices were portrayed as dynamic.

In summary, during the historical science units almost all the scientific claims were supported by evidence (data and warrants) and furthermore each claim was supported by multiple data sources. Therefore, the justification of these science topics was evident in the teachers' arguments. Similar to the experimental topics, however, the teachers rarely used qualifiers and rebuttals. In doing so, a portrait of scientific arguments as dynamic process was largely missing. The scientific arguments constructed by the teachers in the historical units portrayed the epistemic process of science as if accumulation of multiple pieces of data led to a generalized claim.

By comparison, the overall structure of the arguments for experimental and historical science topics was different. In teaching experimental topics scientific claims were not always justified with data. When they were, only one or rarely two pieces of data supported a claim. On the other hand, in teaching historical topics, almost all scientific claims were supported by data and multiple data sources were used to evidence scientific claims. Given that the difference was seen commonly across the four participants, it was more likely because of the difference in modes of inquiry commonly shared by the topics and less due to teaching styles or differences in the specific topics.

<u>Case illustration</u>

The purpose of this case is to illustrate how the scientific arguments utilized by one teacher were similar or different during units on experimental and historical science topics. Gabby's arguments were selected for case illustration because of relatively short but clear examples in the data. Among various scientific claims made during the unit one specific claim is traced and illustrated over multiple days for each of Gabby's units.

DNA unit

According to Gabby, since "there's a lot of stuff on the news and on television… about DNA," the purpose of her DNA unit is to "take off the veil and have them actually understand what it is that they're talking about." She wanted them to understand that "DNA is integral" to biology and, in one way or another, “half the year was around DNA, whether explicit[ly] or implicit[ly]” (pre-instructional interview). One of four scientific claims made during the unit was about DNA structure: “DNA’s…shape is called a double helix.” Gabby discussed the claim over three days.

Gabby provided two pieces of data to evidence her claim. First, she told the story of Erwin Chargaff who “looked at 3 different organisms [and in] every last one of them the amount of adenine was always the same as the amount of thiamine and the amount of guanine was always the same as the amount of cytosine.” This experimental data was warranted to the claim: “because we’ve got the pyrimidines [cytosine and guanine] and the purines [thiamine and guanine] together, [Chargaff’s data] makes it so there’s always a single ring [pyrimidines] bonded with a double ring [purines] and it keeps this whole thing, the sides of it, always equal distance apart.” Thus, here Gabby made a scientific claim about DNA structure supported by a piece of scientific data gathered through laboratory experiments and a warrant connecting the claim and the data: Chargaff’s base-pairing observation [data] helps explain the double helix shape of DNA [claim] because the base pairings keep the DNA strands an equal distance apart [warrant].

As a second piece of evidence Gabby presented Rosalind Franklin’s x-ray crystallography photograph stating, “it was the best picture of DNA that she had taken to date.” She warranted this image to the claim by stating, “what this shape told Maurice, Rosalind, and James… was that DNA was a spiral.” Thus, here Gabby made a scientific claim about DNA structure supported by a piece of data gathered in a laboratory and a warrant connecting the claim and the data: Franklin’s x-ray crystallography photograph [data] helps explain the double helix shape of DNA [claim] because the x-ray showed that the DNA was a spiral [warrant].

In sum, two scientific arguments were made regarding the claim about DNA structure through two pieces of evidence: (a) Chargaff’s base-pairing observations [data] showed that the DNA strands were equal distant apart [warrant] and (b) Franklin’s x-ray crystallography photograph [data] showed a spiral structure [warrant]. By leaving out qualifiers and rebuttals, the image of science depicted in the teacher's argument remained as a straightforward process of justification from evidence to claims.

Evolution unit

For her evolution unit, Gabby described a very general goal of students having a "basic understanding of what evolution is and how it works" (pre-instructional interview). She provided seven scientific claims, all of which were evidenced by data. One of the claims was that "today's whales evolved from a four-legged land mammal." This claim was evidenced by six warranted pieces of scientific data. She began by presenting data, "whales are warm-blooded, give birth to babies rather than lay eggs, and nurse their young with milk. They even have a belly button." This data was warranted to the claim through a statement, "while these animals look and live like fish… they are mammals." Thus, she first established a claim that whales share common characteristics with mammals to build on to a claim about whale evolution.

She then discussed the fossil finds of paleontologists like Philip Gingerich who discovered a <u>Pakicetus</u> skull, a "48.5 million year old land mammal…[with] many wolf-like features [except] that attached to the skull was a set of tiny thickened ear bones." This data was warranted back to the claim through a statement, "the only animals on Earth, living or extinct, that have ear bones thickened this way are the whales."

The next fossil evidence utilized by Gabby was <u>Basilosaurus</u>, a "fossil whale that lived about 10 million years after <u>Pakicetus</u>... [that included] the first hind limbs and feet ever found with a fossil whale skeleton." This was linked to the claim because, as a "huge ocean-going whale with retracted nostrils forming a blowhole halfway up its four-foot-long skull… its body was equipped with legs, but they were too small to support the animal's weight on land." She also showed the students <u>Ambulocetus natans</u> and <u>Rodhocetus kasranni</u>, both of which "were almost as old as <u>Pakicetus</u>… and had legs larger than <u>Basilosaurus</u>." She warranted this data to the claim by stating, "both of these whales found their food in water and were good swimmers, but both still hitched their way ashore to rest and to give birth." In addition, she described further fossil finds of Rodhocetus which were found to have "a tiny hoof in the middle three fingers of each hand" only found today in artiodactyls such as cows, goals, pigs, and hippos. This data was warranted with a statement, "Rodhocetus combined features of an aquatic whale with features of a hoofed mammal all in the same skeleton."

For her final piece of evidence, Gabby stated, "scientists doing DNA studies have shown that the whale's closest living relatives were artiodactyls." This provided confirmation of the fossil find. Therefore, "Rodhocetus was like an arrow pointing backward to a hoofed ancestor and forward to an ocean-dwelling whale."

In summary, Gabby evidenced her claim that whales evolved from a four-legged land mammal with the following six pieces of evidence:

a) Whales have certain characteristics [data] that show they are actually mammals [warrant].
b) The land-dwelling Pakicetus skull contained inner-ear bones [data] only found in modern whales [warrant].
c) The aquatic Basilosaurus had hind legs [data] that were too weak to support its weight on land [warrant].
d) Similarly, Ambulocetus natans and Rodhocetus kasranni had hind legs [data] that showed that while they were aquatic, they came back to shore to give birth [warrant].
e) Rodhocetus kasranni had small hooves [data] similar to that on modern artiodactyls [warrant].
f) DNA [data] shows that the whale's closest living relatives are artiodactyls [warrant].

Gabby's example illustrates how scientific claims were made differently between experimental and historical science topics. Gabby used two pieces of experimental evidence to support the claim about DNA structure while she used six pieces of historical evidence to support the claim about whale evolution. By using multiple evidence pieces the claim in the historical topic unit was repeatedly justified.

In so doing, the epistemic process of science depicted in this historical science topic was the integration of multiple pieces of evidence to support the claim. What was similar between the two topics was the lack of qualifiers and rebuttals, which depicted science as a straightforward process of knowledge construction.

Discussion

The purpose of this study was to compare the scientific arguments secondary science teachers constructed in the classroom for science topics that rely on two different modes of inquiry, experimental and historical. The analysis revealed that less evidence and sometime no evidence was used to support claims during the experimental topic units while far more evidence was used during the historical topic units. The arguments developed by the teachers in both types of units, however, were rather simple in structure as they lacked qualifiers and rebuttals. Scientific knowledge in both types of topics was thus depicted as straightforward argument from evidence to claim without much debate.

One might suspect whether the different amount of evidence used was due to the nature of the topics and not the mode of inquiry in that it is possible that the complexity and scope of the topic could affect the amount of evidence presented by the teachers. The biology teachers, for example, presented far more evidence for the unit on evolution (a broad topic) as opposed to their unit on DNA (a narrow topic). Therefore the increase in evidence could be related not to the mode of inquiry but rather to the scope of the topic. However, the physics teacher still provided far more evidence for his formation of the solar system unit (a narrow topic) than his unit on chemical bonding (a broad topic). This provides evidence that the results are based on the mode of inquiry underlying the topic as opposed to the complexity or the scope of the topic.

Intended or not, the way teachers make arguments during instruction convey images of science that students implicitly learn (Lemke, 1990; Schwab, 1962; Tobin & McRobbie, 1996). The results indicate that the teacher's arguments, while simple in structure, do reflect differences inherent in these two modes of inquiry. These images, however, are implicit in nature. They appear under careful scrutiny and analysis of the research, but are not explicitly described by the teachers to the students. Nor did any of the teachers articulate the difference during the interviews. Therefore, students were responsible for understanding the implicit messages. As a result, the arguments may only have a minimal educational effect on students in showing different modes of inquiry to the students. This is important as, we believe, students should know how scientists construct knowledge differently in different fields of science. The distinction between these two modes of science offers a starting point for examining the diversity of methodologies employed across the sciences.

The results provide implications for classroom practice and research. The findings suggest that teachers should further develop more sophisticated scientific arguments that convey the dynamic nature of scientific inquiry and present these understandings explicitly (Bell, Matkins & Gansneder, 2011). While the participants in this study demonstrated argument structures that are aligned, although implicitly, with the methodologies, the arguments are simple in structure and do not portray the dynamic nature of knowledge construction in science. This suggests changes in what is emphasized during science teacher preparation and professional development. Teachers first should understand the reasoning and methodologies of various modes of inquiry and then link their discourse with the mode of inquiry under study while making their implicit arguments explicit to their students. Furthermore, the dynamic nature of epistemic processes where different knowledge claims are debated and evaluated should be presented in order to convey authentic images of science inquiry as well as better conceptual understanding (Driver et al., 2000; Druker, Chen, & Kelly, 1996; Duschl, Schweingruber, & Shouse, 2007; Katchevich, Hofstein & Mamlok-Naaman, 2011).

This study has implications for the science education research community as well. Specifically, the results reveal the utility of argumentation analysis at the level of the instructional unit. This level of analysis allows for a more authentic comparison of teachers' scientific arguments to those of scientists as teachers often present complete scientific arguments over multiple instructional days. Further research on teacher argumentation at a unit level across various science topics would provide a further understanding of possible connections between topics developed using various modes of inquiry and their manifestation in teacher argumentation. In particular, the less prevalent use of scientific argumentation during the experimental topics shown in this study needs further examination.

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Table 1

Comparing Experimental and Historical Sciences (adapted from Dodick et al., 2009)

	Experimental Science	Historical Science
Epistemic goal	To find general laws or statements	To find ultimate and contingent causes
The nature of objects under study	Uniform and interchangeable entities	Complex and unique entities
Method of evidence construction	Manipulation of nature	Observation of nature
Quality standards	Effective prediction	Effective explanation
Examples	Physics, chemistry, molecular biology, geophysics	Evolutionary biology, cosmology, paleontology

Table 2

Gabby's Experimental Science Unit

Topic	Claims	Data	Warrants
DNA	Shape is a double-helix	Chargaff's base-pairing observations	Showed that the DNA strands were equal distant apart
		Franklin's x-ray crystallography photograph	Showed a spiral structure
	Contained in the nucleus	DNA extraction activity requires soap	Soap breaks up lipid membranes of nucleus
	The chemistry that happens in cells is due to proteins	None	
	DNA is found in all living organisms	Jellyfish fluorescent gene example	Genes from one organism can be activated in another organism

Table 3

Structural Analysis of the Experimental Science Units

Teacher	# Claims	# Data	Claims Supported by Data	# Warrants	Claims Supported by Warranted Data	# Qualifiers	# Rebuttals
Gabby	4	4	3	4	3	0	0
Robert	6	7	5	5	4	0	0
Matt	14	4	4	4	4	0	0
Scott	6	4	3	4	3	0	0

Table 4

Structural Analysis of the Historical Science Units

Teacher	# Claims	# Data	Claims Supported by Data	# Warrants	Claims Supported by Warranted Data	# Qualifiers	# Rebuttals
Gabby	7	34	7	30	7	0	0
Robert	13	38	12	35	12	0	0
Matt	6	36	6	26	5	0	3
Scott	16	57	16	49	16	0	0