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Exploring Opportunities for Argumentation in Modelling Classrooms

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On several levels it can be said that the act of modelling in science is inherently an argumentative act. That is, in virtually all aspects of modelling, from developing a question to judging between competing models that might answer that question, an individual is engaged in persuasive acts. Those acts may be private or public. They may be mental, written or oral, but they are about judging ideas and making sense of them; convincing oneself or others that the ideas and ways of looking at and explaining a phenomenon are useful. These acts are what scientists find exciting. They are what make science intellectually interesting and challenging. Inviting students into this practice is one way to help them learn both the content and process of science. This paper introduces a framework that is attentive to the research on how people learn while simultaneously pushing for curriculum and instruction that engages students in elements of the practice of science. We explore how this framework can be used to foster argumentation by describing the theoretical underpinnings of the framework and using classroom examples to illustrate the utility of the framework for promoting argumentation.

Keywords: Argumentation; Model-based learning; Inquiry-based teaching

Introduction

Increasingly in recent years science educators have been heeding the call for science curricula to do more than present science as a static body of knowledge through didactic instructional practices. Currently, there are a number of efforts aimed at changing classroom practice to bring it in line with a new vision for science learning. Typically, the rationale for these efforts is framed in one of two ways. The first framing provides a
These reformers appeal to what the research says about how people learn and seek to create classroom environments that involve the learner as an active participant in developing understanding and making sense of the scientific ideas that are the target of instruction (e.g. Bransford, Brown, & Cocking, 2003). The second framing provides a vision for science classrooms that mirrors important aspects of science as it is actually practised (e.g. AAAS, 1993; NRC, 1996). These reformers have the goal that students do more than learn science ideas; rather they want students to come to an understanding of the scientific enterprise by participating in activities that are analogous to what scientists actually do.

Importantly, learning scientific content and participating in authentic scientific practices are not mutually exclusive aims. One potential way to satisfy these two aims is to incorporate opportunities for students to engage in argumentation in the science classroom. When argumentation in science classrooms mirrors the salient features of scientific argumentation, it has the potential to support both content learning and authentic experiences. While more research in this area is certainly needed, we take as a central assumption in our work the notion that engaging in argumentation in authentic ways has the potential to support learning across a range of dimensions: from content, to process and epistemology. One key problem facing instructors and curriculum designers, then, is remaining faithful to the uses of argumentation in scientific practice while simultaneously creating engaging student-centred experiences for learners. In this paper we introduce a framework that was developed with the purpose of marrying these two goals; it is attentive to the research on how people learn while simultaneously pushing for curriculum and instruction that engages students in elements of the practice of science.

We begin with a brief overview of theories of argumentation that are reflective of modern conceptions of scientific practice. We then introduce the framework and describe how it can be used to clarify the many ways that argumentation arises during scientific processes by highlighting the central role of models and modelling in science. We end with classroom examples from our research that illustrate the potential of the framework for promoting a range of argumentation points in science classrooms. In this paper we argue for the importance of anchoring science learning in a modelling process. As such, we are attempting to articulate the potential intersections between argumentation and modelling as they may arise in science classrooms. Despite the use of real classroom examples, this is not intended to be an empirical piece. Rather, the contribution here is to the ongoing discussions around what should be included in science education and how classrooms might be framed to add authenticity and conceptual depth.

**Scientific Argumentation in Science Education**

Currently, there is fairly broad consensus as to the value of engaging students in argumentation (NRC, 2007). The rationales for involving students in this particular aspect of scientific practice are wide-ranging and compelling. They include appeals
to create student-centred classrooms where children’s ideas are made explicit and valued (Jimenez-Aleixandre, 2008) and the goal of engaging students in processes that mirror scientific ones with the hope that students will develop a deeper understanding of epistemological issues in science (Sandoval & Millwood, 2008). Curricula that provide opportunities for students to engage in argumentation have the potential to satisfy both of these goals (Driver, Newton, & Osborne, 2000; Duschl, 2008; Osborne, Erduran, & Simon, 2004). Instructional activities that are structured around constructing, articulating, and defending arguments place students at the centre by making them responsible for clarifying their own understanding or providing explanations to others. Engaging students in more active discursive roles can both increase motivation and also create opportunities for knowledge restructuring as students work to make sense of their claims as well as alternatives posed by peers. Several studies have provided evidence suggesting that students can develop a deeper understanding of content when they use it to engage in argumentation (e.g. von Aufschnaiter, Erduran, Osborne, & Simon, 2007; Zohar & Nemet, 2002).

Argumentation is also increasingly seen as a hallmark of authentic scientific learning (Jimenez-Aleixandre & Erduran, 2008; NRC, 2007). Philosophers and sociologists of science recognize argumentation as a central discursive activity of practicing scientists. By inviting students to participate in this practice, the hope is that they will gain an appreciation for the social structure of the scientific community and the epistemic criteria that guide it. Studies that have explicitly attempted to introduce students to authentic forms of scientific discourse report shifts in students’ epistemic commitments (e.g. Sandoval, 2003), suggesting that as students develop an awareness of the importance of argumentation in science, they may learn important lessons about the nature of science itself.

However strong the rationales in the literature are for including argumentation in science education, the fact remains it continues to be a relatively rare event in most science classrooms. Duschl (2008) points out that one possible reason that contemporary classrooms do not reflect philosophical positions taken by the science education community may be a continued misunderstanding of the very nature of science itself. He explains that the persistence of traditional teaching ‘seems to have more to do with the adherence to the old view of scientific methods and to the way schools are run and organized and less to do with what we understand about effective learning environments and children’s learning’ (p. 279). While there is no easy solution to this problem, we contend that clearly identifying an alternative view of science may be useful. In what follows we describe the Practice Framework, which presents a view of the scientific enterprise as one that is centred in model-based reasoning (Nersessian, 1999). This framework will then guide our discussion of some forms of argument that are important in scientific practice and frame our discussion of instructional implications.

The Practice Framework

In the late 1990s the Modeling for Understanding in Science Education (MUSE) group out of the University of Wisconsin, Madison worked to articulate a framework
for guiding curriculum development and instructional practice that was true to scientific practice and implied an active learning stance. This framework came to be known as the *Practice Framework* and has been described in detail elsewhere (Cartier, Passmore, & Stewart, 2001; Passmore, Stewart, & Cartier, 2009). At the heart of the *Practice Framework* is the recognition that model-based reasoning is a cornerstone of every discipline to some degree (Derry, 1999; Frigg & Hartmann, 2008; Giere, 1988; see also Gilbert & Boulter, 1998, and references therein). That is, all scientific disciplines are guided in their inquiries by models that scientists use to construct explanations for data and to further explore nature. Some examples of key models across several disciplines are the particulate model of matter, a model of natural selection, a model of plate tectonics, and a model of force and motion. The development, use, assessment, and revision of models and related explanations play a central role in scientific inquiry and should be a prominent feature of students’ science education.

The *Practice Framework* reflects this model-based inquiry view of science (Figure 1). A benefit of this framework is that it is more realistic than the textbook ‘scientific method,’ which, with its focus on a linear set of steps and controlled experimentation, only represents some disciplines and does not account for the iterative nature of scientific investigation (Passmore et al., 2009; Windschitl, Thompson, & Braaten, 2008). The strength of the *Practice Framework* is that it captures aspects of inquiry common to all disciplines and is therefore general enough to be of value in planning curricula and instruction for any school science area while simultaneously acknowledging the discipline-specificity of inquiry. To be educated in science, students should understand that the methods by which disciplines generate and justify knowledge are diverse and are deployed within practices—communities of inquirers who are organized around discipline-specific models, language, questions, and reasoning patterns (Kitcher, 1993; Stewart, Cartier, & Passmore, 2005). Other scholars in science education have also recently advocated for the role of models and modelling in school science (NRC, 2007; Schwarz et al., 2009; Windschitl et al., 2008). In 2009, Schwarz et al. articulated a learning progression around modelling that is consistent with much of what we have identified in the *Practice Framework*. They have ‘operationalized the practice of modelling to include four elements’: construction, use, evaluation, and revision (p. 635). Each of these elements is present in the *Practice Framework*, but they are further situated within the framework with regard to explanation and discipline-specific norms.

The *Practice Framework* reflects key elements of scientific practice that are useful when designing curricula, making instructional decisions, and assessing students, but does not dictate a linear set of steps or identify a single type of investigative approach. Of particular value is the emphasis on the role of models in: asking questions, recognizing data patterns, constructing explanations for data, and providing criteria for judging knowledge claims. In addition, the *Practice Framework* emphasizes that scientific understanding is embedded within, and inseparable from, the processes by which explanations and models are created, used, evaluated, and revised (Schwarz et al., 2009). This framework thus emphasizes the importance of attending to models in all phases of scientific inquiry.
The Practice Framework focuses on the central role of models in asking questions, recognizing data patterns, and constructing explanations, as well as the criteria for judging knowledge claims. Each of these activities provides obvious points where argumentation is implied. That is, the Practice Framework, by elaborating what the modelling process entails, provides a way to anchor argumentation to various phases of scientific inquiry. For our consideration of argumentation in the context of modelling, we wish to draw attention to a few key distinctions between different purposes and modes of argumentation. Berland and Reiser in their 2009 paper present three inter-related goals of constructing and defending scientific explanations that we would like to apply to argumentation as we frame it more generally here. The first of these goals is ‘sense-making’ where the learner is attempting to bring together evidence with the claims they are putting forward. The second is ‘articulating’ where
the learner is in the business of constructing an argument in such a way that it can be communicated to others. The third is ‘persuading’ where the learner is ‘working to convince their community of the scientific accuracy of their explanations’ (p. 30). Our purpose in connecting to these three goals outlined by Berland and Reiser is to highlight that arguments in science are developed for varying reasons and, as these authors note, these purposes can co-occur and influence one another. That is, one must make sense of ideas in the act of persuading or being persuaded, and articulation is essential for communication. So, although persuasion is often highlighted as the goal of argumentation, there are other reasons that students may engage in argumentation in science classrooms that may have important implications for learning.

A related theoretical issue involves whether arguments in school science require attention to multiple accounts or whether making sense of a single account is a valuable and valid form of argumentation. Some education researchers have argued that asking students to take multiple positions into account is a preferred strategy. Kuhn has suggested that ‘The essential precursor to initiating argument is the generation of different or plural theoretical interpretations’ (1993). Her work has been the inspiration for an emphasis on ‘oppositional accounts’ as lying at the heart of scientific argumentation (e.g. Duschl & Osborne, 2002; Osborne et al., 2004; von Aufschnaiter et al., 2007). Opposition can create the need to craft rebuttals, which are considered by some to be higher quality arguments (von Aufschnaiter et al., 2007). The implication is that oppositional argumentation has the potential to both support conceptual change and reflect scientific practice (Duschl & Osborne, 2002). Alternatively, arguments may feature attempts to generate coherent explanations for a single idea. In such cases students struggle to articulate how their explanation helps make sense of the phenomenon they are attempting to understand (Berland & Reiser, 2009; Mcneill & Krajcik, 2006; Sandoval, 2003; Sandoval & Reiser, 2004). These authors argue that the careful construction of explanations can foster connections among conceptual content as well as mirror the epistemic features of scientific practice. We see the value in each of these approaches, but would suggest that their use may depend on the context. While we agree that being confronted with an alternative account can push students to develop tight and compelling arguments, we can also imagine that doing so may come at the cost of developing a deep understanding of a single relevant explanation. Conversely, the ability to make sense of a single complex idea is a valuable skill, but it may not be enough to stick with students until they have explicitly explored alternatives.

Our main purpose here is to recognize that sense-making, articulating and persuading, and both single and multiple accounts have their place in scientific argumentation, and naturally arise as scientists move through the various stages of scientific practice. Furthermore, we believe that these forms of argument can be practised in classrooms in ways that keep students and their learning at the centre. One final point about these ways of viewing argumentation is that the goals of sense-making, articulating, and persuading may be accomplished in the mind of a single individual, among a small group of students, or in the context of whole class discussion. This is to say that the goals and whether there are single or multiple accounts do not dictate the
classroom structure around which the learner is confronted with sets of ideas. Rather, we believe that the classroom structure is a pedagogical decision that an educator can make when armed with deep understanding of the inquiry process and knowledge of places within that process where argumentation may naturally arise.

Embedded within the *Practice Framework* there are at least four points at which curriculum and instruction can be arranged to promote argumentation. Argumentation (1) may be fostered when students are engaged in determining what to investigate or when they try to bound the problem in some way, (2) may occur as students wrestle with issues associated with research or investigative design, (3) may happen when students are attempting to use a model to explain a phenomenon, and (4) is a natural outcome when students are confronted with judging between models or ideas. In the sections that follow, each of these argumentation points will be discussed and illustrated with classroom examples that have been drawn from audio/video tapes of modelling classrooms or from field notes. These classroom excerpts are used not to argue for the frequency with which these interactions occur in classrooms based on the *Practice Framework*, or the inevitability of those interactions, but more modestly they are used to illustrate the possibility of each type of argumentation and to examine what these arguments might look like *in situ* and how the use of the framework can promote such interactions. As an intentional feature, the *Practice Framework* does not have a single entry point; rather, it is meant to illustrate that entry into scientific practice can occur at a number of different points. So, too, can students enter into argumentation around scientific ideas at a number of different places within an inquiry context. Thus, the four points for argumentation highlighted below may happen at varying and multiple time periods within a series of lessons.

(1) *Interpretation of Phenomena/Asking Questions*

One of the most difficult aspects of scientific practice is choosing an appropriate question—one that is novel, interesting, and testable. The natural world does not necessarily speak in clear and straightforward ways, and modern conceptions of science recognize that while direct observations of nature may have driven scientific inquiry in the past, science today is more often theory-driven or model-based (Duschl & Grandy, 2008; Grandy & Duschl, 2007; Magnani, Nersessian, & Thagard, 1999). Even when curious phenomena provide the inspiration for research questions, it is often because existing models cannot explain them. It is the model then that serves to highlight gaps in our current understanding and invite extension and revision, thereby inspiring novel lines of inquiry. At the same time, the act of constructing or even simply choosing a model can help clarify the goals of inquiry. Natural phenomena are often complex and can be inquired about on a variety of levels. Models serve to constrain inquiry in productive ways by helping scientists define the scope of their investigations. Consider, for example, the phenomenon of moon phases. Attempting to explain why the moon’s appearance changes over the course of a cycle could invoke models of celestial motion, gravity, and/or light depending on exactly how the problem is framed.
Choosing an interesting and manageable question may manifest first as an exercise in sense-making and then in either self-persuasion or as part of a dialogue. Individual scientists undergo this process constantly as they reflect on their own research agendas. Increasingly, the collaborative nature of scientific research means that question articulation is often an exercise in consensus building. In either case, these arguments tend to take place away from the public eye. Typically, the processes that lead researchers to converge on a particular question are distinctly absent from scientific publications (Suppe, 1998). Perhaps this is part of the reason that in typical science classrooms, students are almost never exposed to the complex process of defining and bounding a problem space. Instead instruction often begins with accepted models or explanations, and even if students are asked to formulate questions or hypotheses, they are often asked to do so with regard to an observation or demonstration without any reference to the underlying model. It is not surprising that the questions students generate in these contexts are often either trivial or obtuse. Without a theoretical understanding of the problem, it is difficult to know what to ask. The Practice Framework explicitly addresses the conceptual work of identifying questions worth pursuing (within a particular disciplinary context and with regard to specific models) and thus when used as a guide to curriculum development can lead to opportunities for argumentation around this point in the inquiry process.

Example: defining the scope of the problem
An example of argumentation centred on what question to ask is drawn from a 9-week evolution unit for high school seniors (the curricular approach is described more fully in Passmore & Stewart, 2002). Students were provided with a packet of information on Monarch and Viceroy butterflies and prompted to explain how the similarity in colour came to be. The Monarch/Viceroy example is a canonical one in evolution education and is often used to illustrate the phenomena of warning coloration and mimicry. Here, rather than telling the students in advance that they were being given an example of warning coloration or mimicry in nature, they were simply asked to use the Natural Selection model to account for the similarity in coloration of the two butterfly species. The packets included data about the natural history of both species and limited phylogenetic information. As students began their work they quickly came to realize that using the Natural Selection model to explain the similarity in colour between these two species would require them to first identify a number of specific traits within each population to explain. That is, they came to see that a complete explanation for this phenomenon would actually involve a number of explanations for smaller, more tractable pieces. Deciding on which of these pieces was relevant provided an argumentation context within this class. The following is an account, taken from videotape footage, of the conversation students had about these decisions at the end of the activity.

Teacher: Okay, now since you’ve had a chance to read another group’s argument you probably saw differences. Why don’t you just start throwing those out on the table?
Ali: Just what we said before, that [some groups said] it didn’t really matter what colour the monarch was. We thought that the colour of the monarch was a key factor that made the viceroy what they were. Like if they were brown or something then it wouldn’t work because the blue jays wouldn’t be able to distinguish them. So that [the colour] kept the blue jays from eating them, but also kept them [the blue jays] from eating the viceroy.

Kitty: I just want to say that the reason the monarch’s colour isn’t important is that it could be any colour of the rainbow and it would still be poisonous and the blue jays would still learn avoid it. So what we were saying is that it does matter what colour it was but that it’s not imperative for its survival, whereas the viceroy the variation was imperative for its survival because the variations that were closer to the monarch would survive, but you could have a green monarch and it might get eaten, but if you have other green monarchs...

Nate: [interrupting] I agree with that completely, but one thing that they would have to do, they could be any colour so long as it was different from other species.

Katie: But if it was the same colour of the majority of butterflies then those would still be protected
[bell rings to signify end of period as she says this]
[next class period]

Nate: Can we just go from where we were [yesterday] then?
Nate: The one thing we just left off on, Kitty says that it doesn’t matter what colour it was but we were saying that it could be any colour as long as it was different from the majority of other butterflies but then she said it could be any colour because whatever colour it was the blue jays would learn to avoid. But I think it does matter that it is different from the majority because then the blue jay wouldn’t avoid it because it would have to eat something. And if it was like everything else the blue jay would just have to deal with stomach cramps sometimes.

This conversation is emblematic of the argumentation point around defining the question. More specifically, students were engaged in defining the phenomenon that needed explaining, which impacted the kinds of questions for which they sought answers (see Figure 1). Some students thought that ‘it doesn’t matter what colour’ the monarch was initially because they were just focused on explaining the advantage the viceroy got from being similar. Others thought the colour of the monarch did matter, ‘it does matter that it is different from the majority’, and so they first had to explain the advantage of the monarch’s coloration and then they could explain the viceroy in relation to that. Although the students were initially given the task of explaining similarity in colour between two species, there was still plenty of space for them to define that task. As illustrated by the conversation above, not all groups defined the problem in the same way, and this produced a context for them to engage in argumentation. While some groups felt that any explanation of this phenomenon needed to begin with an explanation for the particular coloration of the monarchs, some groups simply took the monarch coloration as a given and only explained the similarity between the two species. Importantly, all of these considerations were anchored in the model of Natural Selection. The students were attempting to decide how to bring in the idea of selective advantage into their explanations.
With regard to the argument structure, we see elements of persuasive arguments made by individual groups embedded within the context of a class-wide discussion that had the goal of achieving consensus with respect to the question scope. Individual representatives recounted their group’s position often using persuasive language as Ali does in the beginning of the discussion (‘colour of the monarch was a key factor that made the viceroy what they were’). These statements flow into a dialogue in which students are attending to and responding to one another’s ideas rather than blindly attempting to promote a particular position. This is particularly clear in the last quote from Nate in which he goes back and forth between his view and the one he is attributing to Kitty pointing out areas of difference. This multivocal argument arose out of a single task—to explain a particular phenomenon. In the process of attempting to do so the student groups generated plural accounts, and the contrasts between the different interpretations of question scope made it possible for students to consider the subtleties of question formulation. Decisions about where to begin an inquiry and what can be taken as given are important ones in the intellectual lives of scientists and allowing students to participate in this process gives them an opportunity to more fully engage in the scientific enterprise while also providing a potentially rich argumentation context. But again, we’d like to emphasize that the students were constrained by the model they were using. So, while there is room in this type of context for multiple ideas to be generated, it is not a free-for-all. This is an important way in which the modelling classroom promotes a context for argumentation that is likely to foster deeper understanding of the content as well as the process of particular scientific areas.

Methodology

The methods that scientists use will depend on the particular question they are trying to answer. Certain standards of evidence or modelling approaches are appropriate for certain kinds of questions, and these associations are maintained through an ongoing dialogue in the scientific community. In preparation for a particular investigation, a scientist must make the case that the particular methods he has chosen are appropriate either by appealing to community standards or, more rarely, by advancing the case for the utility of a new method or modelling technique. The arguments that support methodology are articulated either explicitly or implicitly in the Methods section of research papers. This section reflects what the scientist takes to be the important features of the investigation, and while we tend to view such sections as including specific experimental procedures or details of model construction, embedded within these descriptions are decisions about the kind of evidence that is needed as well as the assumptions and simplifications the investigator is willing to make. It is understood that these arguments form the basis on which the validity of an investigation will be evaluated.

Too often in school science this important feature of inquiry is done in advance for students, and they are not allowed to see the difficulty and intellectual challenge inherent in figuring out just how to go about answering a question. Unfortunately, students often experience thinking about research methodology in the abstract, focusing on surface features like controls and measurement, without being explicitly anchored
to the particular scientific models being explored. In order for arguments about methodology to productively foster the connection between content and process, students must be engaged in considerations of method and evidence with regard to the model that is guiding the work. For example, given a model of Mendelian inheritance, we would want students to be able to recognize the kinds of genetic crosses they would need to produce in order to gather the data they would need to answer questions about patterns of inheritance. An even greater challenge would be to ask students to participate in the explicit construction of the conceptual or mathematical model that guides the inquiry. In that case, students would have to decide how to construct that model in a way that will shed light on the phenomenon of interest without being so cumbersome as to forestall progress.

**Example: identifying the modelling approach**

This example involves a group of 7 undergraduate students who were participants in a collaborative research traineeship called Collaborative Learning at the Interface of Mathematics and Biology (CLIMB). These students worked with mathematics and biology faculty throughout the year to investigate extended cases in mathematical biology. Over the summer these students were asked to develop their own research project, which means that they were given the unique responsibility of articulating the model that would help them address their question. The following series of discussions, generated from field notes, took place in early spring of 2009 when students were simultaneously developing their question and the associated modelling techniques. By this point the students had decided that they were interested in the impact of different vaccine strategies on the spread of the measles virus. They had read some background literature to gain a foothold on common methodologies. This discussion surrounded a comparison of two papers: one that used a network to model disease spread from person to person, and one that used a set of ordinary differential equations (ODEs) to model spread at the level of the entire population. Professor S, a faculty member, seemed intrigued by the network model, which spurred the following conversation about whether a network model was the appropriate methodology for the measles question.

Professor S: The dynamic network sounds cool, but it may not be tractable.
Lillian: It also plays down the decision making process [of individuals].
Kevin: I like the network thingy. We could use a non-Poisson small-world network.
Sean: We could have a changing network structure.
Lillian: But measles is not a social contact disease.
Nina: Measles is airborne.
Professor S: So do you really believe that it is much more transmissible?
Nina: Transmissibility is high.
Lillian: Small pox is not as easily transmitted as measles.
Professor S: Is that critical? The social network is the network. The only difference is the transmissibility constant, not the nature of the network.
Lillian: Smallpox has a small neighbourhood. Less people get sick who you contact.
Sean: It is probably just a justification to use these simpler models.

Professor S: Oh, I see. My measles network would be larger.

J: Isn’t that just changing the mean network size

... Rose: I have a question. I was looking at the models, and I didn’t understand why some chose the network approach versus differential equations. The whole idea of social contact—some would say we chose a network model to capture social interaction. Others would say, we chose differential equations because a network does not actually reflect social interactions. What I didn’t find is, measles is best done this way.

Professor S: Well it depends on the spatial and temporal dynamics. ODEs are well mixing, mass action, with individuals randomly bouncing around. So SIR models [differential equations] with demography are talking about long time scales. Social networks have no demography, just the spread of the disease. The shortest timescale you care about is who knows whom. So how does the structure influence the spread? It allows for localized interactions—dynamics you would not see in an ODE model.... It’s just a question of what makes the most sense given the question that you are asking. The other way is, you love certain types of models and then you have to ask the right kind of question.

This conversation is just one example of the many discussions students and faculty had together over how to structure their model in ways that were appropriate for the question. In this example, we see students speaking and thinking about science on an equal footing with the professor. An important moment in this discussion is when two students, Lillian and Nina, provide reasons why the network model used to model smallpox may not be appropriate for measles. This move is interesting because it challenges Professor S, and situates these two students as agents with the power to sway the course of the discussion. They encounter contradictory arguments in the literature, which prompts Rose’s question about which model ‘best’ describes measles spread. She is looking for some preferred way to model measles. Instead, as Professor S describes, the students are forced to consider two well-established methods of modelling diseases and choose among them based on the question they have decided is worth pursuing. This decision highlights the complexity and the context-dependency of authentic scientific practice (see Figure 1). In this excerpt, students are primarily engaged in sense-making and articulating (Berland & Reiser, 2009) as they do not yet understand the situation well enough to engage in much persuasion. Having the decision about which modelling approach to use in their hands meant that students had the rare opportunity to both choose a method and provide justifications for those choices. They were asked to decide which methods to use, not simply asked to enact procedures, and as we see in this conversation, doing so allowed them to both engage deeply with the content, the biology of measles transmission, and participate in authentic practice. The argumentation point around methodology has potential to foster deeper understanding of how knowledge is generated in science.
Intersection Between Model and Data

A central goal of scientific inquiry is ultimately to generate explanations (Salmon, 1998). The Practice Framework makes clear the relationship between models and explanations (Figure 1). Briefly, models provide the theoretical structure for explanations. They articulate the proposed mechanisms or the proposed relationships between ideas or system elements (Windschitl et al., 2008). Models are then coupled with data, derived from either experiments or observations, to construct explanations of phenomena. To return to an epidemiological model of disease spread, we see that such models specify the mechanisms of disease transmission. By combining the model with data from observed epidemics, scientists can make explanatory claims about the processes that may have caused the observed spread patterns. Making claims such as these involves advancing particular interpretations of data—a form of argument (Suppe, 1998).

Several recent studies have focused on the importance of inviting students to participate in constructing scientific explanations (Berland & Reiser, 2009; Sandoval, 2003; Sandoval & Reiser, 2004). Many of these accounts focus on students’ ability to relate evidence to knowledge claims. We believe that this task can be clarified when attention is given to the underlying model. It is from this model that claims are derived, and so it is the model that provides a natural structure for suggesting what evidence is needed. For example, if students were asked to provide evidence for claims that a population has undergone natural selection, they would have to appeal to the principles of Darwin’s model and look for evidence of heritable genetic variation that is associated with differential survival and a corresponding shift in genotype frequencies over time. In a classroom that is focused on model development and use, students are asked to be explicit about the connections between particular models and how they are being brought to bear to account for data (Figure 1). Such discussions provide opportunities for students to argue about how data and models go together. That is, classroom interactions can be set up so that students must articulate to one another how a particular model is consistent with the data it purports to explain.

Example—making sense of the seasons

The transcript below was taken from video footage of a ninth grade earth science class studying near-Earth astronomy. This was in the context of a multi-week unit in which the students iteratively developed a model of celestial motion that postulated the relative positions and motions of the Earth, Moon, and Sun. This model was developed to account for many different phenomena such as day/night, phases of the moon, seasons, and eclipses (see http://ncisla.wceruw.org/muse/ for a complete description of the curriculum). The interchange below occurred after a student asserted that the reason for seasons is the tilt of the Earth’s axis with respect to its orbit. While this would be an endpoint in many instructional contexts because the student had given the ‘right’ answer, in this class it was an opportunity for the students (guided
by the teacher) to explore the connections between the model and the data and for one student to argue for his view.

Mr. J. asks the students what causes seasons. Greg volunteers to go the board and draw a picture of his idea. Greg’s drawing shows the Earth and Sun with the Earth tilted on its axis such that the Northern Hemisphere is tipped toward the Sun. He identifies this ‘tilt’ as the cause of seasons.

Mr. J.: All right. So, how many people have actually heard this before in terms of seasons? [most raise their hands] So, yeah, almost everybody. Now the question comes in, ‘How do we explain the data based on that model?’ [emphasis original] Kenny goes to the board and draws a series of diagrams that show the maximum height of the Sun during different seasons. A few students ask him to clarify his drawings and he explains how the Sun appears higher in our sky when the Northern Hemisphere is tilted toward the Sun, during summer. Later, Mr. J. asks the students to explain temperature patterns in different seasons.

Ed: We’re trying to explain why it’s colder in winter.

Mr. J.: Yes, I would like to convince people—

Ed: —well one of the reasons is that when you’re in the winter we’ve obviously found out that the days are shorter, right?

Mr. J.: What do you mean ‘the days are shorter?’

Ed: Daylight shines less.

Mr. J.: Daylight. Thank you.

Ed: And, ah, well when the Sun, the longer the Sun shines on your part of the Earth, or like [home town], let’s say, the warmer it’s gonna keep getting. And if you have a shorter day, shorter daylight period, there’s not enough time for the Sun to heat up you as much. And at night it gets cold and stays cold.

In this example, the teacher asked the students to go beyond merely stating a relationship (the tilt causes seasons) to explaining the connection between an idea and the phenomenon. Specifically, students made the link between the Earth’s tilt and seasonal differences such as angular height of the sun, day length, and temperature, thus making an argument to explain seasons. Here the students are not seen to be arguing with one another; rather the teacher is pushing the students, but it is still important that students are asked to construct arguments that make sense instead of being allowed to simply make statements like, ‘the reason for the seasons is Earth’s tilt’. The resulting dialogue surrounds a single model; no comparison to alternatives is mentioned. While a comparison to other models could have occurred, in this case, the phenomenon was sufficiently complex that it may not have been fruitful to consider alternatives until all understood the nuances of the first model. We argue that attending to the underlying model can support this kind of sense-making by providing a theoretical structure to guide the construction and articulation of explanations. Doing so can provide students with some of the tools they will need to be able to compare competing or alternative explanations. Here the argumentation point that is important is the articulation between data and model. Clarifying this relationship, making it explicit, is too often left undone in many science classrooms, but it provides a potentially
important context for students to engage in argumentation that could foster increased content learning.

Assessing Models or Explanations

Scientists defend their models and the associated explanations according to the criteria through which their arguments will be evaluated. In general, such evaluations occur along two lines: empirical and theoretical (see Figure 1). Empirical criteria assess the degree to which the proposed model is able to explain the data. This is an evaluation of the soundness of the explanation. Is there sufficient and appropriate data in support of the scientist’s claims? Theoretical evaluation considers the validity of the model itself. That is, to what extent is the model internally consistent, and to what extent does it make sense in light of other models? A final consideration concerns how useful the model is as a reasoning tool. It is important to point out that scientists sometimes use models that are known to be ‘false’ (in some sense all models are false) because they are cognitively tractable (Wimsatt, 1987). Thus criteria such as elegance and simplicity may be important as well.

It is in this phase of science that alternative accounts become especially important. Is there an alternative explanation that can better account for the data? Is there a better model that better reflects current theoretical commitments? These arguments are often borne out publicly, and persuasive argument can become central as scientists often attempt to advance their model or explanation over others. Importantly, scientific debates, though not always impersonal, are meant to reflect the criteria defined above. Simply pitting students’ ideas against one another is not sufficient to inspire the deep thought required to critically assess a model. If we instead turn students’ attention to the criteria used by the scientific community, we provide them with the resources to make judgements about alternatives that move beyond comparisons of surface features. It is this type of dialogue that ultimately pushes science forward by highlighting the specific gaps that will need further investigation to reach resolution.

Example—comparing black box models

In this example a group of pre-service science teachers worked with a set of boxes that behaved in a mysterious way. Their task was to collect data on the boxes, find some intriguing patterns in their data, and develop a model that could account for the data patterns they saw. These particular ‘black boxes’ were constructed so that when water was added through a spout in the top, nothing would come out, a small amount would come out, or a large amount (larger than the volume added) would come out. This group of students had investigated the boxes for about 90 minutes, had worked with their group members to develop a model, and had shared their models among their classmates. This discussion picks up as the whole group was trying to come to some consensus about which model they thought satisfied the assessment criteria best. Prior to the groups sharing models with each other, the teacher had worked with the whole class to establish criteria to use when judging models. These criteria were that a ‘good’ [her adjective] model explained the data,
allowed for prediction, was plausible/realistic, and was elegant (these criteria were developed from the Practice Framework, Figure 1). Just before this excerpt the group had been discussing a model that worked using valves that released water at different thresholds.

Layla: I also liked theirs and it doesn’t have the valves which makes it simpler. They had two reservoirs like us, but basically instead of having valves that open and close they say it is a siphon action.

Carson: But how would you get all the water out?

Janet: It is like the bottom part of your toilet.

Carson: But I don’t understand how you get all the water out

Instructor: So Carson why doesn’t that work for you?

Janet: [interrupting] but the toilet bowl empties itself all the way out. I’ve seen it.

Carson: But we’re not talking about the toilet bowl, we’re talking about the tube and reservoir in our boxes.

Heidi: I’ve seen a toilet empty all the way before it starts filling again.

Carson: But you are going to have that little bit left. If you fill that (the black box) up then eventually it drains, but you [with your model] will always have some swishing water left. How does that work?

Rebecca: No cause like when it drains if it is all water in there it kind of pulls itself out. It will all drain. It’s like when you drain a fish tank or something, it all comes out, You use siphoning to get it all out.

Angela: It’s true, a siphon can get it all out

Carson: Okay, I guess I just didn’t understand how that worked.

Here the students are explicitly comparing two models for how the black box works. In the one they are discussing in this excerpt, Carson is questioning how it explains the data that ‘eventually it [the black box] drains’ while his understanding of the model they are proposing would not achieve that. His classmates attempt, by using analogies to toilets and fish tanks, to convince him that, in fact, the model they are proposing can explain the data pattern of complete draining that they’ve seen with the boxes and is consistent with other ideas about how the world works (is plausible). The argumentation is around judging models. Those in favour of the model that depends on a siphon action are using analogies and data to substantiate their claims that their proposed mechanism does account for the patterns they’ve seen. However, the student who is doing the questioning does not understand how their model works, how it can explain the data. In this case, it appears their model relies on a mechanism, a siphon, that this student does not understand and therefore finds implausible. As he continues to question them they have to be specific about how their model works. Again, this is an important contrast to many classrooms in which students present their ideas, but do not engage in analysing them in any way. And, it is distinct from the argumentation point 3 discussed above in that the primary purpose here is to assess ideas whereas in the seasons example the point was to articulate the intersection between model and data.

In the black box example above, students were faced with making a choice between two models. It is important to note that both models ‘worked,’ meaning that they could both account for the data at hand—the empirical criteria were satisfied by each model. However, as noted in the Practice Framework, models in science do not
stand in isolation from other ideas. Because this curriculum was designed using the framework, students had been exposed to the consistency criterion for judging ideas earlier in the lesson and were able to bring it to bear when faced with two models for the black boxes. Thus, the argumentation focused on evaluating two competing ideas using criteria that are reflective of how ideas are judged in science. Here we see the utility of plural accounts most clearly. A side-by-side comparison of two models highlighted the diversity of criteria upon which models can be judged. Students were invited to participate in the epistemic practices of scientists. They were being asked to decide for themselves what counts as knowledge instead of being told what to believe.

Conclusions and Implications

On several levels it can be said that the act of modelling in science is inherently an argumentative one. By this we mean that in virtually all aspects of modelling, from developing a question to judging between competing models that might answer that question, an individual is engaged in sense-making, articulating, and persuasive acts (Berland & Reiser, 2009). Those acts may be private or public. They may be mental, written, or oral, but they are about judging ideas and making sense of them, communicating them to others, and convincing oneself or others that the ideas and ways of looking at and explaining a phenomenon are useful. These acts are what scientists find exciting. They are what make science intellectually interesting and challenging. And importantly, these acts take place in the larger social context of the scientific community who can act as a potential audience, collaborator, or critic. Inviting students into this practice is one potential way of helping them learn content meaningfully and introducing them to the complexities of the scientific process.

We advocate for an integration of forms and purposes of argumentation, as well as the inclusion of both single and multiple accounts. A common pattern across each of the examples we chose to highlight was the use of arguments by individuals or small groups to make sense of ideas that naturally flowed (or at least displayed the potential to flow) into open dialogue when the need for consensus arose. We believe this structure is not far off from the patterns of individual investigation and community discourse that we see in the scientific community. We also chose examples that showed how single and multiple accounts can be useful for different purposes and at different times. Multiple ideas are particularly useful during the planning and articulation phase, when considering many options is crucial to crafting a sensible research plan. Once an investigation has been decided upon, it is important to focus on understanding the implications of that research in detail. Once understood, the ideas can be opened up again to the social processes of assessment and evaluation, which inevitably generate the fodder for new lines of inquiry.

The point we would like to make most strongly in this paper is that situating classrooms in model-based reasoning can have important implications for the discourse and sense-making that students undertake. That is, the model provides an important
anchor to which argumentation can be attached and made productive. Our goal here was to show some explicit ways in which the Practice Framework could be used to identify natural argumentation points. We situated this discussion in a broader consideration of forms and purposes of argumentation so that we could make the point that argumentation in the context of modelling can reflect a variety of authentic practices in science.

Although we believe that arguments of different forms have their use, none can be successful without a well-structured classroom environment. The role of the teacher as a facilitator is crucial to supporting productive argumentation among students. To varying extents, in each of the examples, instructors took a back seat and allowed students to do the majority of the thinking and the talking. However, they also played an important role in defining the goal of the argument and in keeping students focused on the role of the model. The successful application of this framework as a structure for supporting authentic, student-centred arguments depends upon the ability of instructors to both see the value of a model-based approach and convey this value to their students. This clearly points to the need to understand how teachers understand and use curricular scaffolds like the Practice Framework in ways that are authentic to the science and keep students at the centre.

In any given instructional unit it would probably take too long to allow students to engage in argumentation at each point described above, and in no way is this exploration meant to advocate for that position. Rather, the purpose here is to illustrate how seamlessly authentic contexts for argumentation can arise when curriculum and instruction are focused on modelling in science. Developers and teachers can decide when certain argumentation points might be fruitful to further the two aims of reform in science education identified at the beginning of this paper: promoting learning and allowing students to enter into science as it is actually practised. Exactly how this potential can be borne out in reality is an open research question. While the examples we have chosen give us a glimpse of what is possible, we need research that explicitly explores the role of model-based student inquiry in supporting authentic scientific argumentation and ultimately student learning in such contexts. There is little question, however, that engaging students in authentic forms of reasoning is in line with the vision of reform efforts in science education and we argue that situating classrooms in modelling practices may be one way of bringing that vision to life.

References


