Latour Goes to Kindergarten: Children Marshalling Allies In a Spontaneous Argument About What Counts as Science

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Abstract: Elementary school science is often organized around students' developmental limitations and perceived conceptual deficits. Instead, we propose it should build on their strengths and existing competencies. In the current paper we propose the use of Actor Network Theory (Latour, 1987) as a way of framing and examining students' scientific discourse and offering a fruitful approach to recognizing the strengths that young children bring to science education. From this perspective, students' ability to engage in arguments where they enlist allies—including their peers, the teacher, and scientific norms for their scientific ideas and claims—are an important and understudied resource. We present a case-study analysis of six kindergarten and first-grade students engaging in an impromptu debate as an illustration of the proposed analytic frame, organized around the three questions: 1) what is being negotiated, 2) who and what are the actors being leveraged in the negotiation, and 3) how are the actors constructed into networks? We then use our findings to re-define the opportunities for teachable moments in early elementary science education. Our analytic frame serves to highlight the opportunities inherent in those moments within early elementary science classrooms that are not explicitly examples of scientific inquiry, but which nevertheless serve as an opportunity for students to co-construct an authentic understanding of the Nature of Science (NOS).

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Young children are not very good at engaging in authentic scientific activities—so says conventional wisdom. Unfortunately, this notion has a great deal of support in the practice of early science education, despite research which consistently demonstrates that young students are quite capable in contexts that leverage their strengths (NRC, Metz, 1995; 2007). Many of the studies that argue for a limited vision of young children as incapable are grounded either in misconceptions about children's developmental readiness or in a narrow notion of the nature of science (Metz, 1995). By the same token, educators should not assume that young students engage with scientific activities in exactly the same way, and with the same capabilities, as older students or adults. In fact, we would like to suggest that one reason for many of the misconceptions about young children's ability to engage in rich scientific activity stems from the challenges that *adults* often face in interpreting children's interactions as legitimate scientific discourse. Furthermore, we believe that the underestimation of children is often prompted, in part, by an assumption that students' science discourse has to look like idealized adult science discourse: closely tied to recognizable science concepts, directly related to steps in the inquiry process, maximally explicit and coherent. Ethnographic studies of professional science in practice show that this idealization is hardly ever lived up to (Hall, Wieckert, & Wright, 2010; Hall, Wright, & Wieckert, 2007; Kuhn, 1970; Latour, 1999; Latour & Woolgar, 1986). Further, discourse practices relevant to science and epistemologies of science are something that children enter school with, and that can be productively viewed as resources rather than deficits.

Long before they reach school young children have ideas about what is alive and not living, about how things move, and about the shape of the earth. That is, they have intuitions about the content and concepts of science. Just as important, however, is that children have ideas about what is pretend and real, theory and fact, how to convince one another, and ways of regulating themselves and their peers to get things done. In short, they have existing epistemic practices and beliefs that relate to the nature of science. Like children's intuitions, these epistemic practices have the potential to be a resource or a roadblock during science instruction.

These epistemic practices are central to how children come to think about what science *is*—a concept often called the Nature of Science (NOS). One's understanding about the NOS, is tied to how one experiences the practical activity of science in school. However, much of the literature on students' ability or inability to conduct authentic science focuses on the inquiry process, and students' inability to design and conduct experiments to answer a research question. Although effective inquiry is important to the scientific enterprise, the process of "doing good science" involves a great deal more. In fact, the very nature of science, and the definition of effective inquiry within a particular domain is in flux, as scientists collectively define the nature of science through their own ongoing activities, recognizing some activities, theories, processes or concepts as scientific within their domain, and arguing that others are not (Kuhn, 1970). In short, scientists define the nature of what constitutes scientific activity by engaging in it.

With this in mind, the primary goal of this paper is to propose an analytic framework, grounded in science and technology studies (Roth & McGinn, 1997), for understanding students' scientific discourse by attending to places where the students are organizing themselves, other people, and "things" into networks in order to accomplish a goal or support a claim. Further, we explore how educators might use this analytic frame to recognize the social and interactional influences in students' scientific activities. In particular, our focus is on those moments in the early elementary science classroom—such as representing previously learned content to support formative assessment and as a way of helping students clarify their understanding before engaging with new content—that would not fit traditional definitions of "scientific activity" and yet may contribute to students' beliefs about the nature of science. Finally, we provide a framework for examining these moments and identifying opportunities for transforming young children's discussions, particularly their arguments during science class into more productive learning opportunities and / or to transition 'off-topic' arguments into productive science conversations. Our approach complements ongoing success at introducing authentic inquiry into early elementary science (c.f., Lehrer & Schauble, 2006) by examining those moments when students are participating in the social construction of science—defining what science is in their local classrooms—and identifying opportunities to support students in developing a view of the NOS which mirrors the work of practicing scientists. As such the approach we are advocating is a departure from typical science for early elementary children, which generally depend on contrived tasks that are designed to help students memorize previously discovered scientific "facts" without questioning them (c.f., Lemke, 1990; NRC, 2007; Roth, 2005; Sandoval, 2003; White, 1993)

Building on examinations of the day-to-day work of scientists in action (c.f., Latour, 1987), we suggest that it is beneficial to analyze students' interactions in terms of Actor Network Theory (ANT) including the *negotiations* that take place around their scientific activities*, the actors* present in the situation (e.g., the people, objects, and institution as reified in norms and rules), and the way that the students position the actors into *networks* of allies, which students then leverage in negotiating what it means to do science in their classroom. To illustrate the promise of this framework—a focus on negotiations, actors, and network construction for interpreting students' interactions—we will employ it in analyzing a case-study of six kindergarten and first grade students engaging in a debate about one of their peer's representations. In particular, we focus on one exchange in which an extended debate occurred amongst the students despite the fact that the teacher was not present. However, this debate initially seems problematic as it is neither about the science, nor is it resolved in a particularly sophisticated way (at least from a scientific-argumentation perspective). This is exactly why we think it is a good test case for our analytic approach. If we can pull out productive lines of discussion and activity from what appears to be an off-task, non-scientific argument, then the ANT framework has the potential to be a valuable tool in an educator's toolbox to transform mundane interactions into learning opportunities. Furthermore, Latour (1987) suggests that examining science in action necessitates a blurring of the line between science content and the context in which it is created, explored, and evaluated In our case study, this translates into students combining discussions of what a leaf is with discussions of how one can tell if a representation of a leaf is any good; and students moving without comment between voting to determine the status of an object as art or science and proclamations about what they should be doing during science class time. Helping students to understand and navigate these blurred lines will not often *look like* "school science", but has the potential to *be like* professional science.

Our goal in examining this activity through the lens of ANT is thus to focus attention on the way in which students' choices about what to debate and how to support it actually influences their scientific activity as practiced. This impact on scientific practice may have long-term implications for their understanding of the scientific enterprise in general. An examination of the interaction in this light also makes it clear that students are attending to the task they have been assigned (the need to represent a leaf), to the teacher as a representative of institutional authority, and to their peers' opinions. This can first be seen as the students shift their arguments in order to gain the support of their peers by moving away from statements about the location of the blocks in favor of pointed questions about whether or not the blocks are in fact a representation of a leaf (the stated goal of their current activity). Interestingly, the students took their argument one step further and decided to vote on whether or not the blocks represented a leaf. This vote, we will argue, represents the culmination of a process of enlisting allies in support of the students' viewpoints on what constituted a viable creation in their science activities. Our analysis of the process leading up to and including the vote, followed by a brief debate about whether or not a representation of a leaf needs to look exactly like a leaf, will serve to illustrate the utility of an ANT analysis. Given such a framing, students will come to see such activities as scientific, and will in fact develop a notion of what science is from these discussions (Lemke, 1990) regardless of their non-normative nature. Thus, we endeavor through our ANT analysis to identify and support opportunities within these other science activities to help students develop an accurate view of science as a process of negotiation and not simply memorization.

Theoretical framework

Previous research into the ways in which students engage in school science has often acknowledged that by middle school, students think about science in rather unproductive ways, seeing it as a stable body of facts (NRC, 2007; Sandoval, 2005). That is they have an epistemological stance towards school science that is a poor fit with the epistemological stance taken by professional scientists. Though there is still some debate on the topic, educational researchers believe that these different epistemological stances have deep effects on how students engage in science, the degree to which they identify with the discipline, and what they learn. Furthermore, it is quite difficult to change the notion of science as static once it has become entrenched (Sandoval, 2005). The consensus in the science education community, therefore, is to engage students throughout their schooling in a process of learning science that is much closer to the ways in which scientists actually do science—where students are producing and debating scientific knowledge rather than simply consuming it (Duschl & Osborne, 2002). In addition, it is important students begin this authentic engagement with science at an early age in order to participate in long-term learning progressions where new concepts, processes, and tools build off of those that have previously been mastered (NRC, 2007).

In the following sections, we briefly outline the major components of Actor Network Theory, including the notion of science as a process of negotiations, the concept of the black box, and the central role that representations play in scientific activity. In each section, we also briefly review the relevant literature about young children's existing competencies for engaging in the scientific activities described.

Actor Network Theory

One way to describe the process of defining and negotiating the nature of science is Actor Network Theory (ANT), proposed by Latour (c.f., 1987) and other sociologists of science (Callon, 1986). Latour defines science as a complicated web of people, places, theories, representations[1] and practices. For scientific ideas to be accepted by the community at a particular point in time, they need to be supported by the elements of this web; the more support for an idea, the more influence it will have on the field and the harder it will be to change or contradict. From this perspective, students engaging in effective inquiry need to recognize both the role of that inquiry in advancing a scientific argument and the importance of that scientific argument in the context of current scientific theory.

With this interaction between inquiry, scientific argument, representation, and local scientific norms in mind, this paper examines how and when students leverage these resources to help construct local science. We propose that an Actor-Network analytic methodology for interpreting young children's scientific discourse, grounded in Latour's vision of science, can help design, orchestrate and interpret classroom activities and classroom discourse such that these actor-networks are both good science and good learning opportunities for children. Our intention is not to suggest a replacement for inquiry activities, but rather a re-imagining of the activities that already occur around inquiry in elementary classrooms so that these activities serve to support an understanding of science as a process of negotiation.

Negotiations are at the root of scientific activity

Latour (1987, 1988) has identified several important aspects of the process through which scientific theories are developed and gain credibility. First, science is essentially an ongoing argument amongst scientific theories and the theorists that support them. By framing science as an ongoing argument, Latour highlights the fact that the currently accepted theory within a particular branch of science is the one that the majority of scientists in that field have come to believe is true over time. We will refer to this process as a *negotiation* in the current paper in order to highlight the fact that it is often more subtle and less directly agonistic in a classroom environment over a short period of time then the protracted theoretical debates that may occur amongst professional scientists. Below, we identify several components of ANT, and briefly discuss young students' existing ability to engage in similar processes. It is important to note, however, that we are not proposing that students as young as Kindergarten will consistently engage in the kinds of activities that, in adults, would be recognized as scientific. Rather, we aim to identify similar practices in the hopes of pursuing a long-term goal of helping young children employ those practices in their science activities and coming to understand them as part of the scientific process.

[1] Latour uses the term inscription, instead of representation, in order to be clear that he is referring to material representations. However, we have chosen in this paper to use the term representation because it is more common in the science education literature where we aim to situate our discussion.

Young children's competence at arguing and negotiating

Science, as conceptualized by Latour, is a process of constructing, defending, and challenging arguments about the nature of the natural world. Young children also regularly engage in arguments, although they are not often recognized as scientific. In developing these arguments, students often provide justifications for their claims. In one study, children as young as three were shown to argue about their 'rights' to engage in certain activities and provide justifications that were based on an understanding of the consequences of their actions (Dunn & Munn, 1987). Likewise 4-5 year old children were shown to frequently provide justifications during disputes in class and on the playground, although the frequency differed depending on the social context (Orsolini, 1993).

While analyses of scientific argumentation typically conceptualize arguments in terms of a sequence of claims and justifications (c.f., Sandoval, 2003), Latour (1987) proposes that it may be more productive to think of these 'arguments' as a fluid network of actors who can be marshaled as allies or used to discredit one's proposal. In Latour's Actor Network Theory (ANT) actors include people, institutions, and objects. Institutions refer to both collections of people, and the rules that they enforce. Individuals can enlist actors in support of their work in any number of ways simply by citing them (in the case of people) or by using them (in the case of objects or techniques) or generally building upon the ideas or tools that comprise different actors or networks.

In order to challenge a theory, it is necessary to discredit one or more of these different components, many of which have stood the test of time. Furthermore, the larger the given network in terms of the number and quality of the actors that constitute the network, the harder it is to challenge the theory or claim that it represents because it becomes necessary to discredit the larger network of proven and supported actors.

By eight years of age, children seem to be competent in creating and manipulating networks of actors to support or discredit claims. In a study that compared the arguments of 2nd, 5th, and 8th graders, little difference was found between the relative frequency which 2nd and 8th graders provided supporting evidence (approximately 60%) and produced counter arguments (approximately 40%) (Leitão, 2003). Further, the students' rationale for choosing to include a justification was consistent across age groups. Even second grade students were choosing justifications based on whether or not they thought them to be true, if they thought others would accept them, and if they were consistent with their own position. Thus, despite being limited by having less content knowledge to draw on, by second grade students have a rhetorical awareness about the structure of arguments and of how to marshal allies.

Young children also have a well-developed sense of the conditions in which actors themselves might need further support. For example, when analyzing the sequential organization of 4- to 5-year-old's arguments Orsolini (1993) showed that children were anticipating and pre-empting requests for justifications during disputes. Similarly, Sheldon's (1992) comparison of how 3-5 year old boys and girls argue noted the ways in which children's arguments showed an awareness of other people's points of view. She found that in same-sex pairings, girls showed a greater tendency towards "double-voiced discourse," or discourse that was oriented towards both one's own goals and simultaneously including other points of view. For example, in arguing over the distribution of pickles, one girl said she wanted a whole pickle, to which the other responded she would give her a whole half of a pickle. Sheldon (1992) argues that double-voiced discourse in disputes promotes solidarity of the group and consensus. In contrast, boys in same-sex pairings tended to use more single-voiced, authoritative discourse. However, in mixed-sex groupings the trends were less clear cut, with girls using more single-voiced arguments. Both sexes made efforts to tie their statements to the talk of their interlocutors (M. H. Goodwin, 1990), suggesting that both girls and boys changed their rhetorical strategies to align with their audience.

More evidence that children have at least an implicit awareness of the need to coordinate one's own claims with the perspective of another comes from studies of pretend play. When pretending, 3- to 4-year-old children demonstrate the ability to transform one another's ideas by modifying the previous turn, providing complementary or related information, or extending or generalizing an idea (Verba, 1993). Further, they are able to specifically react to attempts to persuade them by expressing their own desires and attempting to gain their interlocutor's approval (Verba, 1993). Other studies show that 5-year-olds are able to engage in an argument in reaction to another's statement or assertion. Although not as skilled as adults, with the right support these five year olds were able to incorporate other points of view in their own talk (Orsolini & Pontecorvo, 1992). Compared to adults, children use more emphasis, less provisionality, and often re-doubled negations.

Black Boxes

In many cases, we take for granted the kinds of actors that may be enlisted, and some actors are so common as to be beyond question, a process that Latour (1987, 1999) refers to as black-boxing. This process, while essential to efficient scientific practice is not entirely benign, since "scientific and technical work is made invisible by its own success" (Latour, 1999, p. 304). It is often necessary to open the black box and reconsider its component actors in order to advance the field (Fountain, 1999). In educational contexts, the notion of the black box is problematic not only because it obfuscates the tentative nature of the knowledge represented by the black box, but also because it hides the heterogeneous nature of the actors that are black boxes (Roth & McGinn, 1997). Understanding a science concept in depth often requires both placing it a larger network of ideas as well as opening up the details of the concept itself including its history.

There is also an unfortunate parallel between the notion of the black box, and what Duschl (1990) refers to as "final form" science, a focus on currently accepted scientific beliefs without any acknowledgement of the process through which they became held as beliefs. The reason black-boxing and "final form" science are so important—and problematic—is that this may promote in students an epistemological stance that scientific facts are beyond reproach, and that science is not in fact a process, but simply the memorization of facts, a perspective that is incommensurate with professional scientist's vision of science (Sandoval, 2005). Therefore, it has been recommended that students engage in argumentation, debate, and discussion around scientific "facts" as a way of helping them to develop a rich understanding of the both the concepts themselves and the process of scientific development (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Duschl & Osborne, 2002). There is some evidence that a constructivist epistemological stance that acknowledges science as a process in this way also allows students to more fully benefit from engaging in activities such as learning through inquiry (Sandoval, 2005). In the present context, we interpret the literature that critiques classroom cultures which appear to promote the learning of "final form" science as a recommendation that students be supported in opening up the black-boxes of their current scientific knowledge and practice. This process helps them to engage in more "authentic," productive scientific activity.

Representations

While many different kinds of actors play an important role in the process of developing and spreading scientific theories, representations play a particularly central role (Latour, 1988; Roth & McGinn, 1998). Drawings, diagrams, and charts allow us to document, arrange, transport, share, and combine information (C. Goodwin, 2000; Latour, 1988; Roth & McGinn, 1998). They often play a central role in conducting scientific inquiry, as a tool for collecting data or generating models (Lehrer, Jenkins, & Osana, 1998; Lehrer & Schauble, 2000). They also play a pivotal role in how scientists extend and refute each other's theories. Representations allow scientists to compare and contrast information, and thus, the majority of the work in which scientists engage does not involve observing the natural world; rather, much scientific work is conducted with and in response to representations (Latour, 1987, 1988). As Latour points out representations and models, or as he calls them inscriptions, are at the heart of the process of "purifying" the concepts of science from the often messy process of science.

Representations such as these are also common in early elementary science classrooms. Unique to this setting, representations are frequently used to help students reflect upon and express their current understanding in ways that teachers can leverage for formative assessment (Erickson, 2007). These moments when students are asked to represent their current knowledge in order to help refine their understanding are easily overlooked in analyses of science activities because they are not intended to introduce new concepts to the students, but rather to help ensure that they understand the content they have already encountered. And yet, students often examine, express, adapt, and police the local norms of science within these representational activities (Author, 2007b; Author, 2010), suggesting that these activities may also play a role in students' developing scientific epistemologies.

In contrast to how they are often presented in school, during the process of making or coming to understand science, the act of representing goes beyond unproblematically documenting one's observations of the world in some material medium. Rather, when representing a phenomena, we make choices about which details to include, and how to include them in the representation (Palmer, 1977). Think back to the example of the clay bee with a too-long tongue. By making these choices, we are selectively highlighting, or minimizing the importance of certain features of the represented world, we are influencing how the world is perceived by those viewing the representations (Lynch, 1988). These features then shape our engagement with the phenomena being studied. For example, children in the classroom described below initially drew leaves as a simple outline, reflecting their understanding of the leaves as a unified whole. Over the course of the curriculum, however, students began to learn about the veins in the leaf, and their role in transporting materials to and from the other parts of a plant.[2] These veins then took on added importance, and students included them in their drawings as a way of labeling the leaves. Later discussions about plants and their processes then benefited from students' drawings that included the veins as a key feature.

Long before they attend school, students can recognize the symbolic nature of representations (DeLoache & Burns, 1994), and as a result can productively engage in creating models as a way of engaging in science learning, despite the fact that they do face a number of challenges in constructing scientifically normative models (Lehrer & Schauble, 2000). In particular, students in kindergarten and first grade are less likely to include many of the details in a representation that their older peers recognize as being important for conveying the character of the object being represented (Tversky, Kugelmass, & Winter, 1991). However, there is reason to believe that these developmental trends are, at least partially, attributable to students' ability to recognize and follow representational norms and criteria that are honored in their local classroom context (Author, 2007b). In fact, students not only attend to representational criteria in their local classrooms, but debate and enforce them (ibid). This is a key point of departure for the present analysis, as our current focus is not on the normative nature of the students' representations, but rather upon the process through which the students recognize and negotiate the criteria for their representations (much like professional scientists do).

Actor Network Theory in Education

In the previous sections we have reviewed literature that shows that young children can and do argue and, in doing so, are constructing networks of claims, warrants, evidence, and rebuttals that are responsive to context and audience. Further, students often enlist representations into these discussions as support for their own positions. From an ANT perspective, these are exactly the kinds of skills necessary to marshal allies and advance an argument in science. What is not clear is how to link these informal competencies to formal contexts during science instruction in ways that mirror the *process* of professional scientists. It has, after all, taken thousands of years for science as we know it to come to this point. If, as we argue, students' natural competence for engaging in developing networks of allies can be effectively leveraged, we may be able to refine or design curriculum for early elementary science classrooms that are more likely to help students understand the nature of science as a process and not a series of authoritative facts.

We are, of course, not the first to suggest using ANT to address issues related to science education. Roth and McGinn suggest that educators should be aware of the social conception of knowledge presented by Latour and others. Moreover, educators should use this knowledge to inform their curricular decisions both in terms of the content to be presented, and the process through which it should be presented (or engaged with) by students (Roth & McGinn, 1997). Roth and McGinn (1998) also build off of many of Latour's (1988) ideas about inscriptions as central to the work of science, suggesting that students use of inscriptions should be viewed as a form of social practice. Rather than

[2] It is worth noting that this process can also be explained in terms of the students' being encouraged to open up the black-boxed conceptions that they previously held regarding leaves.

examine students' inscriptions for their match to those of professionals, Roth and McGinn propose an examination of both the social practices that surround the effective use of inscriptions by professionals, and those that the students themselves employ. Otherwise, we may mistakenly assume that students misunderstand the principles that scientists assume as relevant to particular inscription systems, when, in some cases, the students may simply be unfamiliar with the process of constructing and using the inscription itself in productive ways. Our argument extends this line of thought. We suggest that it is necessary to look at the entire social system in the science classroom, including but not limited to students' inscriptions as a way of understanding how the students are participating in and co-constructing a local definition of science.

In a similar vein, Fountain (1999) suggests that ANT can be used to examine and enhance science education. To accomplish this, she suggests explicitly teaching students as young as grade seven about ANT. Similarly, Richard and Bader (2010) propose that an ANT-grounded conception of the social nature of science serve as the basis for conversations about the NOS whenever it does arise in classroom contexts. Our proposal is more modest. We suggest ANT is a powerful tool for helping to understand and trace students' actions in these kinds of classrooms as a way of both identifying their resources, and making sense of the outcomes. By examining students' scientific activities in terms of a negotiation between networks of actors, we can begin to focus on the process through which their ideas are co-constructed in a classroom, and how this shifts over time. Furthermore, identifying those actors that students rely upon as allies can help to reveal both their conceptual understanding, and their beliefs about which actors are important in their classroom context. We can then begin to more accurately answer questions regarding the capabilities of these students to engage in authentic science.

Methods

In order to illustrate the process through which we believe young students can and do engage in marshalling allies within science classrooms, we present an in-depth analysis of one case-study episode. The case-study episode was videotaped as part of a larger study conducted within a kindergarten and first grade mixed-age classroom at a progressive elementary school in southern California. Findings from the larger study were presented in Author (2007a, 2007b). Twenty-one students consented to participate in the study. The students typically engaged in a combination of whole-class discussion and work within groups of 5-6 students. The members of this classroom regularly engaged in activities that involved creating, discussing, and critiquing representations of the students' ideas. Thus, the activity we describe below was not novel for the students in this classroom.

This was a participant observation study in which the first author participated in the classroom in a role similar to a teaching assistant for an average of 2 hours a day, three days a week, which was the average amount of time devoted to science. Starting after 2 weeks in the classroom, one video camera was used to record the students' science activities. The corpus of video data was analyzed using techniques grounded in discourse analysis (c.f., Duranti & Goodwin, 1992; Erickson, 2004, 2006) in order to document the students' representational practices, as well as the way in which they came to participate in these practices. In this paper we present analysis of one case study—the vote episode—that highlights many of the ways in which the students engaged in argumentation around their representational practices.

In reviewing the corpus of video data, the episode to be presented stood out as a unique opportunity because the teacher was not present for the majority of the interaction, and while the researcher may have inadvertently highlighted some of the students' contributions, the students were largely responsible for the direction that their debate took. In particular, this episode is interesting because the students resolve part of their disagreement by holding a vote. The vote that took place was striking in that while voting was commonplace in this classroom, it had never previously been used to vet a product as a valid creation in science. As such, this episode is a unique opportunity to examine the kinds of scientific inquiry young students are capable of when properly motivated and allowed to engage in this kind of debate.

In order to analyze the data within an ANT framework, we sought to answer three inter-connected questions: 1) What is being negotiated?; 2) What are the actors?; 3) How are the actors being constructed into networks? We answered each of these questions iteratively, documenting and then revising candidate answers as we iteratively reviewed the data. The answers presented below are those that we arrived at through negotiation and review of the data. For this reason, while we present the answers to each question in sequence, it should be noted that each answer is dependent upon the other two. It is not possible, for example, to define the nature of the negotiation without attending to the actors. Conversely, in order to identify the actors of relevance, it is necessary to first identify the negotiation to be discussed. Nonetheless, we found it to be a fruitful analytical exercise to answer all three questions separately in order to articulate the mechanisms and implications of the process of negotiation. Therefore, we present the individual answers to the questions in Figure 1, and then present the analysis of each episode in a more integrated and fluid form in the analysis section below.

[Insert Figure 1 about here]

What is being negotiated?

As noted above, we first identified a meta-negotiation in order to narrow our analytic focus. The main topic of our analysis was the debate about the disposition of one particular wooden block that culminated in a vote before shifting into a debate about the nature of representations. Focusing on this meta-negotiation allowed us to identify the sequence of negotiations that furthered this general thread of argumentation, and to exclude from our analysis any additional threads that did not seem relevant. Notably, we excluded any conversations that took place between students who seemed to be temporarily attending to alternative topics such as their own representations.

To help identify key moments in the negotiation process, we identified traditional markers of argumentation such as claims and counter-claims. These markers then lead naturally to the actors and networks to be described below as those who presented claims and counter-claims were the first actors identified, and then the content and nature of their claims lead us to the other relevant actors.

As we identified these key moments in the negotiation process, we further sub-divided the case study into four episodes, each coinciding with a notable shift in the topic and process of negotiation. This then allowed us to document and contrast the actors and networks as the students progressed through each of the 4 sub-episodes. For a summary of the episodes, see Figure 1. This was an iterative process, with our sub-episodes shifting as we revisited our analysis and the process of negotiation in increasingly complex detail.

What are the actors?

Once we had identified the different stages of negotiation, we then reviewed the actors that we believed were part of the negotiations. Actors in this case included people, institutions, and objects as mentioned above. When looking for institutions in the data, we were examining the rules, norms, and authority figures that the students appeared to make relevant to their discussion. For example, the institution of school was most often made relevant as the students referred to the teacher or the rules that the teacher had specified for their activity. As suggested above, a review of the literature reveals that young students are quite capable of engaging in arguments and responding to local norms and rules (c.f., Orsolini, 1993; Sheldon, 1992). What we aim to contribute to the literature is the way that they can leverage these capabilities while engaged in resolving a dispute about scientific products. Also, there is a danger that an over-reliance upon the teacher-cum-authority as support for student ideas runs the risk of framing science as only those facts that the teacher agrees with. However, we suggest that a detailed analysis of the warrants that students select for the claims will inform instructional practices which can identify and address this misconception if and when it does occur.

How are the actors constructed into networks?

In order to examine the creation and use of the networks of actors in the students' debate, our goal was not to examine each isolated statement within the arguments. Instead, we identified those lines of argumentation that became relevant for the students and examined the process through which they were made relevant. Lines of argumentation that were not picked up were also examined as a point of comparison to those that were. Because the students were largely unsupervised, there was also a great deal of activity that appears to have been completely off-topic, and was not relevant to the students' themselves as they engaged in their argument. It is obviously not possible to say for sure what was relevant to the participants, but we identify actions or words as relevant if they appear to have a direct influence on the students' ongoing activity, and in particular if the students refer to these other actions in their debate. For example, at one point in the episode, two of the students, Caitlyn and Sara, had a separate discussion about the representation that Caitlyn was making. This discussion happened off to the side of the work area in hushed voices, nobody else appears to have overheard it, and it does not appear to directly precede a move on either of their parts relating to the larger discussion. Therefore, we assume that these actions are similar to other actions in the students' lives. They may have influenced the students' themselves but did not directly impact the interaction that we chose to analyze. For this reason we do not report these other actions and activities. For the sake of clarity, we also exclude these interactions from the transcript.

Finally, we wish to remind the reader that our goal in examining this episode is not to suggest that the students were engaged in inquiry, nor were they exploring ideas that were new to them. However, because they were asked to create scientific representations during a portion of the day that was identified as "science time", it is clear in their discourse that they are identifying aspects of what does and does not count as scientific in their interactions. As such, this is an opportunity for them to continue to co-construct what "science" is within their classroom. For this reason, the initial phases of the debate are still relevant for analysis because they represent a moment when the students are engaging in what they consider to be acceptable and relevant aspects of science. Furthermore, this kind of opportunity is commonplace even in elementary classrooms that consistently engage students in inquiry activities, and as such is important to examine.

The Vote Episode

The vote episode took place during an activity that was roughly halfway through a 12-week unit on the life cycle of plants. The curriculum had begun with students drawing and painting leaves from observation. As the students began noting consistent features across the leaves, such as the presence of the veins, the teacher also explained the role of these features and asked the students to conduct experiments, when possible, to further explore the role of these features (e.g., inserting food color in the water of cut-flowers to be able to see the movement of that water through the stem and into the leaves). The class then engaged in a series of activities in which students were asked to represent leaves using a variety of materials so that they could demonstrate their understanding of the features that a leaf has, and begin whole class discussions about the purpose of these structures. The teacher intended for these activities to help students review and express their understanding of the parts of the leaf, and also to provide the teacher with an opportunity to assess the students' current understanding and introduce new activities as needed. The vote episode took place during one of these activities when one group of six students, aged 5-7, were asked to represent leaves using wooden blocks in the area just outside the classroom door. While wooden blocks might seem a challenging and non-normative medium to represent an item such as a leaf, this teacher frequently used them as a format for helping students to explore ideas quickly and easily in three dimensions. Also, this activity tended to be more collaborative than other representational activities as the students were asked to work together to create their leaves. This was intended to promote discussion about the characteristics of the leaf that were not as evident in other representational forms such as creating individual drawings. Finally, this activity was intended to focus on the structures of the leaf while later activities shifted to focusing on the functions of those structures once it was clear that the students all understood what the key structures were.

On the day of the vote episode, Mrs. English[3] (their teacher) briefly reviewed the structure of the leaf with the entire class. This review included a description of the function that the leaf plays—to create food for the entire plant—and those features of the leaf that are important to include when representing it, the stem, veins, and blades. Michael (7), Sara (6), Robert (7), Jackson (7), Lynn (6), and Caitlyn (7), were asked to create sculptures of leaves using wooden blocks. We will briefly summarize the vote episode before returning to a more in-depth analysis of each stage of the episode.

[Insert Figure 2 about here]

The students began the work with enthusiasm and worked without supervision for about 8 minutes, creating representations of leaves both individually and in pairs. Their

[3] All names are pseudonyms

'science work' was interspersed with play, singing, conversation, and other seemingly off-topic activity, but steady progress was made on the construction of 4 different representations of leaves using wooden blocks. Our analysis of this episode begins with a disagreement between Robert and Lynn about the nature and location of a block that Lynn has placed. The episode ends with the students organizing themselves to vote on Lynn's representation. We are particularly interested in the process through which the students negotiated the representational status of Lynn's blocks. Their discussions about whether a sculpture needs to look like a leaf, what type of leaf, and who should be able to easily 'read' the representation are particularly informative. Their discussions specifically point to what students believe are relevant standards for scientific representations and how young students go about negotiating science tasks when there is no teacher present.

The disagreement started when Robert walked across the play area, pointed at Lynn's block, and claimed that it did not look like a leaf. At about the same time, Jackson, who was making his leaf in the area next to Lynn, tried to move Lynn's block. He accused Lynn of making her leaf too close to his own, a charge that Lynn denied. Sara attempted to defend Lynn by arguing that Lynn didn't mean to have her block too close to Jackson's. The researcher videotaping the event also jumped in at this point and asked Lynn what part of the leaf the controversial block was meant to be.

The researcher's remark may have inadvertently brought together two disconnected arguments over Lynn's block: whether it was a balance beam (as opposed to a leaf) and whether it was too close to Jackson's leaf. As things escalated in intensity—marked by several loud cries from Lynn and Jackson—Michael, as of yet uninvolved in the dispute, joined the interaction. Michael initially appeared to be taking Robert's side, pointing out that Lynn's block looked like a balance beam, not a leaf. However, the importance of his joining the fray was not which side he took, but that now four of the seven students were involved in the dispute. From this point on, the dispute drew in all seven students (and to some degree the researcher behind the video camera) and focused only on the issue of whether or not Lynn's sculpture was, or was not a leaf. Michael facilitated this shift by taking center stage and organizing a vote on Lynn's representation before proclaiming the results of vote: the block was not a leaf but it was a "work of goodness." At the close of the episode Michael built on the momentum of the vote to discuss what qualities have to be present for the sculpture to be a leaf, and whose sculptures qualify.

Analysis

In order to present our analysis this episode, we have identified four sub-episodes of analytic interest. These sub-episodes, summarized in Figure 1 represent four key stages of negotiation about: 1) the placement of the block; 2) what is being made; 3) categorizing the creation; and 4) debating the kinds of leaves being created, and the process of representing more generally. As noted above, these phases coincide with natural changes in how the students were participating, what they were saying, and the way in which they were aligning themselves with the task and each other. We will present the sections in order below. Within each section, we will first summarize the sub-episode, and then present our answers to the three guiding questions sequentially. Line numbers will be continuous in order to see where each section lies in relation to the others.

Episode 1: Negotiating the placement of the block

Episode 1 began when Robert and Jackson both articulated critiques of the block that Lynn was placing. While neither of these critiques survived to the end of the negotiation in its initial form, this episode is valuable because it allows us to trace the process through which both Robert and Jackson adjusted their critiques in order to gain support from the other actors present, particularly the other students.

This is the kind of interaction that might be easily ignored as a simple disagreement between children that can be resolved in an equally simple manner using any of a number of common classroom management techniques. However, our ANT grounded analysis suggests otherwise. We see this as an opportunity, a moment of potential that could transition into a productive and more scientifically normative debate. As we will demonstrate below, the ANT analysis helps to draw our attention to the fact that, initially, the actors that the students are relying upon as they construct their networks may not be scientific (e.g., personal preference) and also that many of those actors are black-boxed in ways that do not support productive discussion. As we will demonstrate in Episode 4, it becomes necessary to open the black-boxes in order to challenge them and further the students' negotiations. This episode is also valuable for analysis in that it begins to highlight the tension surrounding the block as both a material object and a representation. The representational role of the block is ultimately the one that is both privileged, and debated.

Excerpt 1: Negotiating the Disagreement[4]

1	Robert:	(You guys), that doesn't look like a leaf ((walking towards the blocks in question))
2	Lynn:	***Stopi::t***!
3	Jackson:	I don't want you **to connect**!
4	Lynn:	I'm not con**nect**ing **it**! ((kneeling, returning her block back to it's original position somewhat closer to Jackson's))
5	Jackson:	You're **about to**::. ((Caitlyn who was watching the exchange returns to her own creation, and Michael is now turning away from the window and focusing his attention on what is happening))
6	Lynn:	No I'::m not.
7	Sara:	She's not trying to!
8	Robert:	We aren't supposed to make balance beams! ((standing on top of one of the longer blocks))
9		(2)
10	Researcher:	What are you making there? What is that part you are standing on?

[4] The transcription conventions used are adapted from Jefferson (2004) . Double parentheses identify descriptions by the researcher, typically to describe gestures. Parentheses identify speech that was difficult to transcribe. Parentheses with a number in them represent elapsed time (in tenths of seconds). Double obliques (//) represent overlapped speech. Bolded text indicates when participants raised their voice.

11		(.5)((some mumbling in the background))
12	Robert:	(**She**) made a balance beam.
13	Lynn:	No I did~not.
14	Robert:	Yes.
15	Lynn:	No
16	Jackson:	(I don't) I don't like it there Lynn.//
17	Researcher:	Lynn, I think it's dangerous, so you shouldn't, you shouldn't walk on //that.
18	Jackson:	Lynn, I don't like it there.
19		((Lynn steps on the block))
20	Researcher:	Lynn (.1) can you-
21	Robert:	Lynn, ***don't*** walk on it!
22		.2
23	Jackson:	We don't want that to-
24	Robert:	It looks like a balance beam ((moves the pieces off the "stage))
25		.8
26	Jackson:	((loud cry from Jackson though it is unclear what he is saying))
27		We don't **want it** so close! ((Lynn is putting the pieces back on now.))
28	Lynn:	***Sto::p it***! ((Robert is moving the block with his foot))
29		***Stop***!
30	Jackson:	The other way around, like
31		Put that one here, and that one there ((pointing with his foot))
32		((more background mumbling))

The framing of two arguments and their supporting actors.

The line of argument that Robert initiated addressed the question of whether or not the block was a leaf or a balance beam. This distinction is important because it relates directly to both the institutionally promoted task (creating leaves) and the status of the block as either an object (balance beam) or a representation (of a leaf). Interestingly, while Robert began by stating that the block doesn't look like a leaf (line 1), the rest of his comments during the initial phase only address the question of whether or not the block is in fact a balance beam. It seems implicit that by being a balance beam, a block would therefore not be a leaf, but more importantly, if the block is a balance beam, it is not a representation and therefore does not require additional interpretation. By framing the block as a balance beam instead of consistently addressing the issue of whether or not it represented a leaf, the status of the block as a balance beam may not have been clearly linked to the task in the students' minds, and may be one reason that Robert's line of argumentation does not initially serve to invite the other students into the discussion.

However, Robert continued to focus on drawing the larger group into his critique and questions about the status of Lynn's construction. This attention to garnering support, both from the other people present and from the rules or norms, begins to highlight for us the importance that the students place on the group in making decisions about representations in this classroom's science activities. It is unclear whether Robert's attempts at marshaling the other actors as allies led directly to the other students joining the discussion, but in the end they did join, and the attention of the other students was the first step in initiating a vote on whether or not the block was a representation. This suggests that, in practice, addressing the group instead of the individual with whom one is arguing can often be an effective technique in a debate.

In contrast, Jackson's focus was not about the nature of Lynn's block. Rather, Jackson argued that Lynn's block was too close to the leaf that he was creating with Robert, and he wanted it moved. While Jackson did not address the group as a whole, he did implicitly enlist Robert as a supporter by referring to him as the co-creator of the leaf with phrases like "we" and "our." However, not only did Robert never explicitly add his support to Jackson's argument, but Sara also chose to enter the argument by defending Lynn (line 7), demonstrating the fact that Jackson's appeal to his own personal preferences was less effective then the other appeals to the nature of the task. While this appears to be an obvious conclusion, its importance will be made more clear below when we document Jackson's shift in what he was arguing about.

When a block becomes a representation instead of an object.

When examining the two parallel arguments about Lynn's block, it is also important to note that the 'battlefield' over which they occur is the representation that Lynn is working on, in the form of the block that has been placed in a specific location on the floor. Jackson's argument initially only attended to the material location of the block—a line of reasoning that did not gain support from any other students and was soon dropped by the students (including Jackson). For the rest of the students and the remainder of the episode, however, this block is not evaluated as a block placed in space, but as part of a representation of something. This appears consistent throughout the students' interactions that we observed. Once we move beyond the kinds of arguments that are common to young children's joint activities, such as access to shared space and materials, representations take on a particular role in arguments that require discussion and debate, particularly in cases where appeals to norms and scientific facts take precedence over personal preferences. This importance appears to parallel the privileged role that Latour (1987, 1988) and others assign to representations within the scientific enterprise.

When attempting to decide what a representation needs to include, it would certainly be possible for the students to appeal to a specific justification presented by a teacher or another source. However, these students are instead appealing to the nature of the task as defined by that authority figure. The importance of this difference is that by appealing to the nature of the task, the students use the appeal to define the rules of the debate, not to resolve it. Resolving it is then based upon the students' own interpretation of the representation and the norms surrounding its creation. In other words, their interactions demonstrate that the question to be addressed is whether or not the block represents a leaf, not whether or not the teacher believes it represents a leaf.

This seemingly subtle difference is an important one when we examine the nature of the students' scientific activity. It reveals a context in which students are enabled to debate the interpretation of a representation rather than simply arguing over the correct answer to the question. This leads to multiple possible "right" answers, and in fact several types of representations survive to the end of the activity, each satisfying the need to be a leaf in a different way. This plurality of acceptable solutions to a problem with tacit agreement upon the underlying criteria again parallels the work of professional scientists who often reach slightly different solutions even when they do agree upon the key criteria for an acceptable solution.

Re-defining the dispute moves it closer to a scientific argument

The specific conversational moves and justifications that Jackson, Robert, and Lynn used to advance their arguments match the literature on young children's justifications within disputes (c.f., Orsolini, 1993; Sheldon, 1992). In fact, we see much of this in the current example, including Robert's referencing of rules when he said "we aren't supposed to be making balance beams" (line 8) and Jackson's argument from perceived consequences of Lynn placing her block when he said "I don't want you to connect!" (line 3).

However, when we step back to examine the activity structure in which these justifications are happening, as well as the flow of the argument over time, we see that the collective impact of these moves and counter-moves ultimately led to a redefinition of the terms of the argument, as the students privileged certain types of justifications over others and as some actors were proven to have or provide greater support than others. While not yet a discussion of the science concepts, it is relevant to science because the students are treating science activities as negotiated; they are engaging in science which is more than simply knowledge-telling or following the rules of school, but includes the ability to justify one's choices or challenge those of a peer. To paraphrase Latour's (1987) description of networks that are better at resisting attacks, it was a lot easier to counter Jackson's preference than the rules of the task since the rules were in turn supported by the teacher who has far more authority than Jackson.

Episode 2: Negotiating what is being made

In this section we briefly analyze the shift from two parallel arguments about Lynn's block to a whole-group discussion that resulted in a vote about whether or not the block was a leaf. While this episode is less analytically rich than the others, it represents an important transition from episode 1 to episode 3, and highlights the degree to which young children marshal allies in the way that Latour (1987) argues that scientists do. The phase began with the researcher asking Jackson what he was creating. As Jackson answered, Robert began moving Lynn's block with his feet, leading to a yell from Lynn. At this point, Michael took visible notice of the block and began to ask Lynn whether it was a balance beam or a leaf (line 46). At this moment the interactions shifted with Robert and Jackson both asking Lynn what kind of leaf the block was instead of referring to it as a balance beam or an inappropriately positioned block, respectively. This phase highlights the factors which contributed to this debate becoming the one to which all of the students' attended and, in the process, highlights those aspects of the science activities that the students find relevant to discuss, negotiate, and privilege.

In addition to highlighting the process through which the students develop their networks of allies, the ANT analysis also brings to the fore the fact that several of the actors remain black-boxes at this point. Again, this presents a moment of opportunity where, had the researcher who was present been thinking in terms of ANT, he might have encouraged the unpacking of the black-boxes (which doesn't in fact occur until episode 4). Furthermore, ANT highlights for us the implications of the researcher's questions for the students—by asking about the leaf, the researcher appears to remind the students of the fact that there is institutional support for the creation of leaves, which may be one reason for the shift in the negotiation to considering the block not only as a representation, but as a representation of a leaf.

Excerpt 2: Enlisting Allies

33	Researcher:	Jackson, what are you trying to make over there?
34		-0.5
35		Jackson ((now he looks up))
36		What is that you're making?
37	Jackson:	A ***<u>leaf</u>***.
38	Researcher:	What kind of leaf is that?
39	Jackson:	We ***dunno***.
40	Researcher:	Can you show me the parts?
41	Jackson:	((mumbling))
42		-8
43	Researcher:	Robert //(.) ***Robert***? ((as Robert is moving the pieces up and down with his feet now. Michael is now right next to Lynn's block looking at it moving up and down for a brief moment, Sara and Caitlyn are paying attention again…))
44	Lynn:	((Lynn yells quite loudly at this point, but it is difficult to understand what she is saying.))
45		.2
46	Michael:	(It does) sorta look like a balance beam you know?
47		.3
48	Michael:	And we're not building// balance beams, ***are we***? ((turns up towards Sara as he says are we))
49	Robert:	***What*** are you making any:way?
50	Jackson:	That's not even a leaf ***Lynn***.
51	Robert:	She said to make the leaves, ***Lynn.***
52	Michael:	What kind of leaf is it?
53	Jackson:	°That's ***no:t*** a le:***af***.
54		***I say that's not a leaf***! ((standing off to the side, raising his hand to point as he finishes his statement – Lynn now moves outside of the focus of attention.))

Using Justifications to re-frame the nature of the debate.

The excerpt above began with the researcher asking Jackson what he was making. His response that it was a leaf but that he didn't know what kind prompted the researcher to ask what the parts are. While there was no directly observable impact of this brief exchange, it may have served to remind Jackson of the current task and lend some additional authority to that task because an adult voiced it. This also begins to highlight the institutional rule that for a representation of a leaf to be valid, it must include a pre-determined set of parts. This interpretation is supported by prior research suggesting that students begin to notice and learn from patterns of teacher questioning and shift their behaviors accordingly (Erickson, 1996, 2004; Orsolini, 1993). Furthermore, as we will see below, Jackson was able to answer similar questions when the primary teacher asked them at the end of this episode.

At the same time, Robert asked Lynn for the first time what she was making (line 49), while Jackson added the comment "That's not even a leaf" (line 50). Robert then pointed out that "she" (whom we can infer is the teacher) said to make leaves while Michael asked Lynn what kind of leaf she was making. What is important about this collection of questions is that all of the children who were addressing Lynn at this point were now evaluating her block as a representation, and using the standard of satisfying the task constraint of creating a leaf as a way of evaluating her representation. This was no longer a set of disjointed disputes. Instead, it became a whole-group debate over whether or not Lynn had created the right kind of representation. The allies—including the other students, the task constraint of creating a leaf, the teacher as the source of that task—had been marshaled, and the debate had now been framed in a way in which everyone was willing and able to participate.

It is not possible to say definitively whether this convergence occurred because Lynn's yell caught everyone's attention, because Jackson and Robert noticed that they were not achieving their goals and changed them, because the researcher inadvertently reminded the students of the current task, due to pure happenstance, or to some combination of factors. However, it does appear that the students were on-board with this shift; they did not just repeat the researcher's questions back at Lynn. Instead, they combined a series of arguments, demonstrating that they were able to perform this new argument. This demonstration suggests that the shift in argument was not simply happenstance, but a result of the task constraints combined with local interactions. More importantly, we see here how the students leveraged their awareness of the situation and their ability to frame an argument in support of local scientific activity.

ANT also draws our attention to a potentially problematic aspect of the negotiation at this point in time: the idea of a representation of a leaf is still somewhat black-boxed. Despite the fact that the students have begun to question what kind of leaf the block may represent, and the researcher highlighted the need to include particular parts, the students are still treating the idea that the block is a leaf as a simple either-or proposition. Although the children have not yet transitioned to talking about the science concepts, the interaction is important because is shows how black-boxed ideas can be counter productive to talking science. Black-boxes are akin to diSessa's p-prims (1993)—simple conceptual building blocks, grounded in observation, which students use to reason about the world—in that students believe that these ideas stand on their own and need no further explanation. However, unlike p-prims these are cultural constructions and can be opened up, and students should be encouraged to do so. In the current example, the students will ultimately open the black-box on their own, while in other cases the teacher may take such a moment to encourage such a re-evaluation of the representations in question.

Episode 3: Negotiating whether the block is a work of goodness or a leaf?

The vote phase describes the conclusion of this initial debate about Lynn's block. Now that the students appeared to implicitly agree that the relevant question was whether or not the block was a leaf, Michael requested a vote on whether or not the block was a leaf, or a work of goodness, and the students voted. Michael then reported the results—that the block was not a leaf. From an ANT perspective, this episode appears to be important for a few key reasons. First, by resolving the either-or debate about the leaf, it seems to facilitate the movement of the students beyond the need to address social issues such as Jackson's frustration and the potential need to save face for Lynn, and sets the stage for opening the black-box in episode 4. Also, we see here the possible dangers inherent in student reliance on networks of allies without guidance about what might constitute appropriate networks. They rely upon the majority opinion and create a clear power dynamic, which may put Lynn in a very awkward and intimidating position. In other words, the vote, which seems at first blush like a very exciting moment of impromptu democracy, also needs to be evaluated in terms of the way that networks of allies may impact the losing side.

Excerpt 3: The vote phase

55	Michael:	Raise your hand if you think (that it's just) a work of goodness
56		(.05)((Michael and Sara raise their hands. Caitlyn appears preoccupied with her own leaf construction.))
57		And not a leaf. ((Lynn, then Jackson raise their hands now. Caitlyn stands up, turns towards the group, pauses for a moment while looking at the blocks in apparent thought, then raises her hand))
58		-0.05
59		That means it's ***not a leaf***.
60		And that's one, two three four five ((while turning his head to count))
61		That's five. And who thinks that it ***is*** a leaf?
62	Lynn:	I didn't say it ***is*** a leaf. I said it's not a ***balance*** beam.
63	(Jackson):	I don't like it (one bit)
64	Michael:	I say it's a work of art, and it would be ***not*** a leaf ((stands up and moves toward stage now))
65		and it's considered ***not a leaf*** here Lynn ((The entire group is standing around Lynn who is squatting on the ground. Michael gestures with the block he is holding as he makes each point.))
66		it's a work of art. It's ***good*** ((steps towards Lynn now))

67 but it's ***not a*** leaf.
68 (Jackson): Yeah, Miss English said to make le***a:ves***.

What it means to vote about a leaf.

In calling for the vote, Michael demonstrated two key ideas that his peers ratified simply by being willing to vote.[5] First, Michael has shown that a student can call a vote in the absence of an authority figure, such as a teacher. By raising their hands to vote, all of the students, including Lynn, ratify this move, and claim the agency to interpret a representation. They are in effect asserting that this is something that anyone can do, not just teachers, and that the results of their decision are considered valid for their class. In fact, the importance of the majority opinion was further demonstrated by the fact that Michael directed his question to the group while Lynn was standing behind him. Lynn also voted against her block being a leaf, despite having largely remained quiet as the discussion of her block took place.

Second, Michael framed the vote in a way that demonstrated that the question to be answered was whether or not the block was a leaf as opposed to a work of goodness. He did not mention a balance beam, or the proximity of the block to Jackson's representation. Again, by voting (instead of ignoring Michael, challenging the categories, or appealing to the researcher for intervention), the students demonstrate that they were at least willing to go along with this interpretation.

It is important to note that Lynn's responses can also be explained by her being in the minority opinion, and also having been somewhat intimidated by her peers—especially when we notice the way they were all standing above and around her as she crouched down upon the ground (see Figure 3). It certainly seemed intimidating to the researchers who have reviewed this video! It is difficult to say for sure what role this may have played in Lynn's decisions. However, to the extent that Lynn may have been intimidated into ratifying the majority view here, it serves to confirm the importance of garnering the support of one's peers and other authority figures in this science classroom, and the importance of helping all students to be able to engage effectively in such a process.

[Insert Figure 3 about here]

Episode 4: Negotiating the kind of leaf, and the nature of representations

At the conclusion of the vote, while discussing the results, Michael noticed Jackson's blocks and asked what kind of leaf it was. When Jackson responded that it was "just a leaf", Michael then preceded to discuss the fact that the students' leaves did not all look like leaves. Robert began to counter that the representations did not have to be perfect. Here is where the conversation began to turn towards what everyone can

[5] Some readers might suggest that perhaps Michael is simply a more "popular" student, and that is why the students all voted. However, there are several instances in the data leading up to the vote when Michael suggests that the entire group create one representation together and is ignored. This suggests that either the content or circumstance of this vote is somewhat unique.

recognize as science. It looked like a debate would ensue about what exactly needed to be in the representation (e.g. stem, veins, etc.) for it to count as science. Unfortunately, while we can gain some insights from the beginning of this debate, it ended rather quickly when the students discovered a spider. Despite its unsatisfying conclusion, however, this episode is important because it helps to highlight the productive shift that occurs when students are able to open and challenge the black-boxes that they are working with. This episode highlights the potential benefits of encouraging moments when students do open up the black box, and highlights additional opportunities as new black-boxes are introduced in the process. It also reveals that, at least in this sample, the networks that the students create can be quite fluid, as the students begin shifting their allegiances almost immediately from those who the agreed with on the prior issue to those who they agree with now. In other words, new networks of allies that are more relevant to the current negotiation move into the fore.

Excerpt 4: The discussion phrase

69	Michael	What kind of leaf are ***you making***? ***Come*** to ***think of*** it Jackson? ((Michael points at Jackson's blocks as he moves towards them))
70		0.5
71	Robert	We don't know, but it's just a leaf
72	Jackson	(from nature)
73	Michael	***Well,*** we made a ***regular*** kind of leaf that everybody (knows)
74	Sara:	We're making, like
75		the leaves that're going like this and this and (this and this and this)//
76	Jackson	(it)// looks like a tree ((pointing at his leaf))
77	Michael	Let's admit it, let's admit it. Let's admit it.
78		All of our leaves,
79		we ***do not*** know what they are
80		and they don't look like actual ***leaves***. ((said while circling the space, ends at his own representation))
81		Except for ours.
82	Sara:	Yeah
83	Jackson	Hey, (it's not…)
84	Robert	And it doesn't have to be perfect
85	Sara:	Yeah, and it doesn't have to be-
86		Spider!

This follow-up to the vote is important in part because it shows that Lynn was not the only student whose work could be or was questioned. In questioning the other students' work, Michael also forced the students to recognize—and to a degree, debate—the question of whether or not a representation of a leaf had to look exactly like a leaf (i.e., whether visual fidelity to the referent is a valid criteria for judging a representation). Finally, this discussion foreshadows the later discussions that the teacher had with the students while reviewing their leaves.

Does a representation of a leaf have to look like a leaf?

When Michael said, "they don't look like actual leaves. Except for ours", he highlighted an important aspect of scientific representations: the question of which features need to be included. Michael emphasized his opinion that it was important for a representation to look like an actual leaf. While this may seem naïve from the standpoint of normative science representations that might instead privilege only those details necessary for conveying a specific idea, it does reveal some important ideas about the creator of the representation and the audience—both should know what the leaf is. This can be seen in line 77 when Michael asks the students to admit that they don't know what their leaves are aside from him (and Sara, with whom he collaborated). He then adds the further distinction that it needs to look like the actual leaf in line 78. Jackson appeared to take affront (line 83), though he was not specific why. However, Robert disagreed, pointing out that the representation did not need to be perfect.

These beliefs about science representations reflect what diSessa and colleagues (A. A. DiSessa, 2004; A. A. DiSessa, Hammer, Sherin, & Kolpakowski, 1991; A. A. DiSessa & Sherin, 2000) have referred to as meta-representational competence or MRC. MRC represents a general set of understandings or beliefs about how to create representations, including an awareness of how science representations need to reflect their current task environment. Such understandings are central to the enterprise of science, and in this case represent students' early understanding of those principles that should (or should not) be applied to creating and evaluating science representations.

While this debate remained unsettled, what is important is that it demonstrates another way in which the students were participating in an authentic version of science in line with ANT—they were debating the criteria that the collective should use to evaluate individual contributions. Furthermore, later classroom work revealed that the students responded to norms established by the teacher and re-enforced in student discussions such as this one in order to transform the standards to which they held their own representations accountable, adding additional details that were considered important (Author, 2007b). Not only were the students contributing in an ongoing basis to the definition of science that was acceptable within their classroom, but this notion shifted over time, much as it does in professional science (though somewhat more quickly).

Finally, this episode shows that the students were boxing back up the discussion. It opens with the words "come to think of it…" a move that takes the whole argument, which was just assembled against Lynn, and uses it to "level" the other group's models. Black-boxing up a network and using it in a new context or on a new problem is a powerful and common move in the professional practice of science. In line 73 the re-boxing of the idea is complete with the title of a "regular"[6] kind of leaf, a simple enough phrase that encapsulates both the earlier argument about what constitutes a scientific representation and what constitutes an adequate representation of a leaf. For the present episode, this remains unchallenged. However, later classroom activities address the diversity of leaf forms, effectively unpacking this black-box and helping the students to

[6] While the students never explicitly articulated what they meant by a "regular" kind of leaf, their representation resembled a willow leaf—a shape that was commonly discussed in class.

recognize that while certain features are common, their arrangement isn't always the same.

The teacher mirrors the students' treatment

While our current focus is on the way in which kindergarten and first-grade students may interact with minimal adult interaction, it is worth noting a few key details concerning the teacher's response to the students' representations. Mrs. English's response to Michael and Sara's representation was to say, "that is definitely a leaf", and "it really does look like a leaf" confirming their belief that it was easily interpreted as a leaf.

Importantly, the teacher also ratified Robert's position that the leaf did not have to be "perfect" by saying that the leaf he created with Jackson was "beautiful." However, before this evaluation, Mrs. English first asked some clarifying questions, such as where the veins were. These clarifying questions reveal one possible area of importance in terms of the students' experience of the project. These questions revealed that both arguments present in the finale of the vote episode were accurate in the teacher's eyes. Mrs. English confirmed that it was acceptable to make a leaf that doesn't "look like a leaf" so long as the key parts can be identified. Her questions also supported the students' appeal to specific cultural as a straightforward way of judging the validity of a representation of a leaf without interpretation. While it is unclear whether or not the students learned these two lessons, it certainly demonstrates how their practical day-to-day work fit within this set of norms. More importantly, it illustrates that, at least on this one occasion, they were able to rise to the challenge.

Discussion

We have suggested that Actor Network Theory (ANT) provides a useful analytic frame for examining students' interactions in science class, both for teachers and researchers who wish to engage young children in modeling activities and scientific argumentation. More specifically, we have proposed that it is helpful to apply ANT to examining interactions by attending to 1) what is being negotiated; 2) what actors are part of the negotiation; and 3) the process through which the actors are constructed into networks of allies. Given these three observations we suggest that we look for opportunities to 1) move the discussion towards a deeper discussion of science concepts and the nature of science; 2) assess what is relevant to the students and use them to identify resources that can be built upon or refined; 3) open up the black-boxes that are hiding students' unwarranted assumptions. Our focus has been on analyzing those activities in early elementary school science classrooms which are not recognizable as inquiry, and yet which do help to define students' understanding of the scientific enterprise. In order to illustrate the process and benefit of this kind of analysis, we have examined an extended case study in which students begin with a seemingly innocuous debate about the placement of a wooden block and then transition to a promising, if short-lived, exploration of what a scientific representation needs to look like. We specifically chose this episode because it is the kind of episode that might otherwise be overlooked for its lack of rich, recognizably normative scientific debate, and because of the way that the students progressed somewhat naturally through several forms of negotiation, with minimal teacher intervention, culminating in unpacking some of their own assumptions as they negotiated the nature of representations in their science classroom.

Over the course of the four episodes we saw a trend towards an increasing focus on the science (e.g. leaves and their properties), and an increasing focus on what counts as science (e.g., fidelity of representations). The intellectual progression in this case started with an opening up of a black-box and ended with the re-boxing of their activity and network/argument. In the first episode we see off-task activity being critically examined and spring-boarding students into a discussion about how one evaluates a representation based on the nature of the activity in which they are engaged. By the third episode we see the students recognizing their agency in this newly defined space and orchestrating a vote to settle the question of Lynn's representation. The vote per se is not as important as their recognition that they can decide what does and does not count. These important issues, however, are not settled by objective facts or by outside authority. Instead, they are settled by the construction and interpretation of networks in the same ways that Latour argues that scientific facts are constructed. Finally, in the last episode we see the students adapting their networks to better fit their audience and context, and fluidly changing their positions based on the perceived strength of the resulting networks. We also see the students boxing the argument back up into a black-box that, at least for these students, can be re-directed at other models without having to re-visit the whole debate.

Implications

Much of what takes place in early elementary science classrooms does not look like normative scientific inquiry. However, there are good reasons for this, including the fact that asking students to represent their current understanding offers an opportunity both for students to rehearse and refine this understanding, and for the teacher to observe and assess this understanding. We have argued, however, building on the foundational work of Lemke (1990) that these activities also play a role in shaping students' understanding of the scientific enterprise. Furthermore, we suggest that these activities represent an important opportunity for helping students to leverage their existing ability to engage in argumentation to begin viewing science as a process of negotiation.

Furthermore, thinking about what we have called moments of opportunity from an ANT standpoint, we see the potential for rethinking the notion of a "teachable moment." Typically, such moments are seen as opportunities to present new information to students because they are ready to receive it. This superficial framing contradicts constructivist approaches to teaching and learning. In contrast, by viewing those moments as part of an ongoing negotiation of what science means, it becomes possible to frame the placement of such opportunities within a larger context of helping students to develop rich networks of allies that address valuable scientific topics.

For designers, researchers, and educators this means considering what types of activities, teacher moves, and social norms are required to encourage moments where students open up the dual black-boxes of content and of process. Our case study does not provide grounds for definitive answers to these questions, but it does suggest some possibilities. First, in order to promote a discussion of what makes an adequate model students need to a) make models and b) compare and evaluate their models with a critical eye. We have found that in early education often teachers are reluctant to engage students in critiquing their peer's work, as they are explicitly trying to build students' social skills and pro-social behavior. However, as the vote showed, the role of a critical friend can be quite compatible with a social skills curriculum. In our case the alternative to having produced a scientific representation was to have produced a "work of goodness" a phrase that was consistent with the school's social skill's curriculum which emphasized "put-ups" instead of put downs. Second, in order to promote a discussion of the exact nature of their activity during science, students need to have the agency to explore and press the boundaries of what science is. Clearly, this type of exploration is at odds with the more common goal of efficient coverage of material. However, we argue that developing a more accurate understanding of the Nature of Science clearly outweighs a superficial understanding of the science concepts, especially at this age.

These two features—modeling and agency—set the stage for the productive integration of meta-discussion and debate about the content of science and the process of doing science. However, opportunities still must be seized and shepherded in productive ways. Our analysis highlighted the fact that students are naturally attuned to the process of leveraging allies and constructing networks to support their positions in an ongoing negotiation. However, not all students have equal access to networks of allies and the processes of developing such networks. As Erickson points out (1996, 2004), some students are more facile at playing this "game," and as a result have more privileged access to the kinds of interactions that will make them successful in school. Our belief, however, is that attending to the shifting networks and negotiations that we have proposed will help to highlight some of these imbalances, as well as suggesting a process for alleviating them by helping students to develop equivalent and competitive networks. Our ANT analysis provides guidelines for specific moments in which opening up black-boxes might be most productive. We also highlight the ways that a teacher might steer a teachable moment by introducing or supporting new actors that students might incorporate into their existing networks.

Timing of openings. We see several key features of the timing of opportunities or openings in the present analysis. First, students began to spontaneously engage in debates as result of engaging in work in a shared space where their work was open (Hutchins, 1995) and accessible to their peers. Inline with our previous findings (Author, 2007b; Author, 2005), students naturally and spontaneously engaged in critical discourse about their representations simply by being allowed to work publicly and in close-proximity with each other. This suggests the benefit of considering students' work from a collective and social perspective even when they are being asked to produce individual constructions. In future work, it may be possible to model for students how to engage in this kind of critical and spontaneous work in a productive manner so that these sessions of co-located individual work can increasingly tap into the benefits of social interaction for the students.

Second, as noted above, the students had an open solution space. They were given the opportunity to create a number of different and divergent products, which made it possible to then debate the validity of each of these differing solutions. We have noted in our own data that while students may disagree or discuss their work, they are less likely to debate it when they recognize that the teacher will only accept one idealized format for a final answer. Inline with the literature on problem based learning (c.f. Hmelo-Silver, 2004), future designs might leverage this notion by explicitly encouraging students to recognize the benefit of multiple solutions to the same problem while encouraging students to be reflective and explicit about the more general criteria that they hold their products to. In the present study, the teacher frequently pursued such a path by reminding the students explicitly that it was ok to represent one's ideas however they liked, so long as certain features were included.

Third, these opportunities existed only because the students were allowed enough agency to pursue the lines of argumentation that naturally arose. We believe that the freedom that the students had, despite being a double-edged sword, did afford them the opportunity to identify and then pursue those lines of argumentation that were immediately relevant and meaningful to them. It should be possible, therefore, to construct such moments by giving students freedom as they begin their scientific inquiries and then observing the lines of argumentation that may arise. Similarly, teachers may allow the students to explicitly identify and select those criteria that they would like to debate, rather than pre-determining lines of inquiry in a manner reminiscent of IRE classrooms (Mehan, 1979). Such a focus on student-generated criteria for what counts as a problem and a solution to the problem can productively scaffold students in developing and then critically evaluating their own solutions in light of the shared criteria that they have established (c.f. Author, 2005).

Finally, it appears in the present analysis that certain kinds of social-interactional issues had to be settled before the students could settle in to more productive and grounded scientific work. It was only after Jackson was challenged to revise his criteria and the discussion of Lynn's block was resolved with a vote that the students were able to focus on the scientific business at hand. Our finding that the science content learning was dependent on the quality of social interactions suggests that in similar situations, it will be beneficial for teachers to identify and resolve interactional issues before pursuing task-relevant questions. Alternatively, it may be possible to encourage students to make this transition as part of the classrooms norms—to privilege grounded claims about the nature of content or representations as carrying more weight in an effort to explicitly promote and facilitate the kind of transition that we observed.

The shift toward more scientific conversations. As noted in our analysis, a crucial component in the shift from naturally arising or superficial argumentation to more normative debate was tied heavily to the need to open and challenge the black-boxes present in the classroom, and the students' ongoing discussion. In the present example, this began to happen as a result of unresolved discussions and attempts to further one's own social goals (as Michael may have done in the final episode). This also seemed to be heavily tied to the students' understanding of the assigned task. In a few cases, the researcher who was present seemed to have unintentionally promoted this shift. By inquiring into what kind of leaf they were making, the researcher explicitly asking the students to at least partially open their own black-box. In future designs, we believe that these partial successes might be codified and studied in more detail in an effort to explicitly draw students' attention to the black-boxes with which they are operating. Curriculum might specifically involve asking the students to identify and then make use of questions or other practices for challenging and opening up black-boxes. Such designs might be similar in form to the successful work related to reciprocal teaching, which so successfully encouraged meta-cognitive activity on the part of students by scaffolding them in adopting roles related to the work of successful readers (Palincsar, 1986), Translating this to science classrooms, students might be asked explicitly to take on the role of challenging existing notions—or opening black-boxes—which may encourage students to more consistently engage in this enterprise

We have found the ANT analysis presented within this article to be valuable in its ability to help make salient these many issues around students' scientific practices, particularly in those activities that, while common and important in elementary science classrooms, are not representative of scientific inquiry. Future work can now apply this methodology to new data sets, and begin to articulate the actors that students are most likely to use in different contexts, as well as the processes of negotiation that are most beneficial for students. Furthermore, we believe it is possible to begin thinking about how to reorganize instruction from the ANT perspective, and therefore help students to directly and explicitly challenge their black-boxes— leading to the collective definition, production, and defense of knowledge in classroom environments—as they construct networks of allies. Such an approach has the dual benefits of preparing young students to engage in authentic scientific activities and leveraging their often un-tapped existing communicative and interactional competencies.

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	Episode 1	Episode 2	Episode 3	Episode 4
1. What is being **negotiated**?	Placement of the block: • current location • someplace else	What is being made: • balance beam • leaf	What is it: • work of goodness • leaf	What kind of leaf was created: • regular • other Do representations of leaves need to look like real ones? • yes • no
2. What are the **actors**?	• The block • Three students • Personal preference • Minimal institutional support [Shift to a larger, institution al network]	• The block • Most of the students • The researcher • Ms. English and the task (Black Boxed) • Fidelity • (Black Boxed)	• The block • All of the students • Expectation of put-ups • Voting as an approach to resolving multiple perspectives • Art / Science [• Closing the social issues, • Opening the black box]	• All of the students • The researcher • The fidelity issue opened up • Expectation of not being perfect • Regular leaves • Being recognized as a leaf
3. How are the actors being constructed into **networks**?	• Michael and Jackson position themselves against Lynn's block placement (individually) [Shift to the task]	• The researcher inadvertently provides new criteria for the debate with institutional support • Enlisting of the teacher and other students *attempted*	• The vote is used to establish the majority network • Jackson seems to be particularly impassioned	• Reference to criteria (teacher, task, etc.) • More direct counter-claims

Figure 1: A summary of the four case-study episodes organized in terms of the process of negotiation

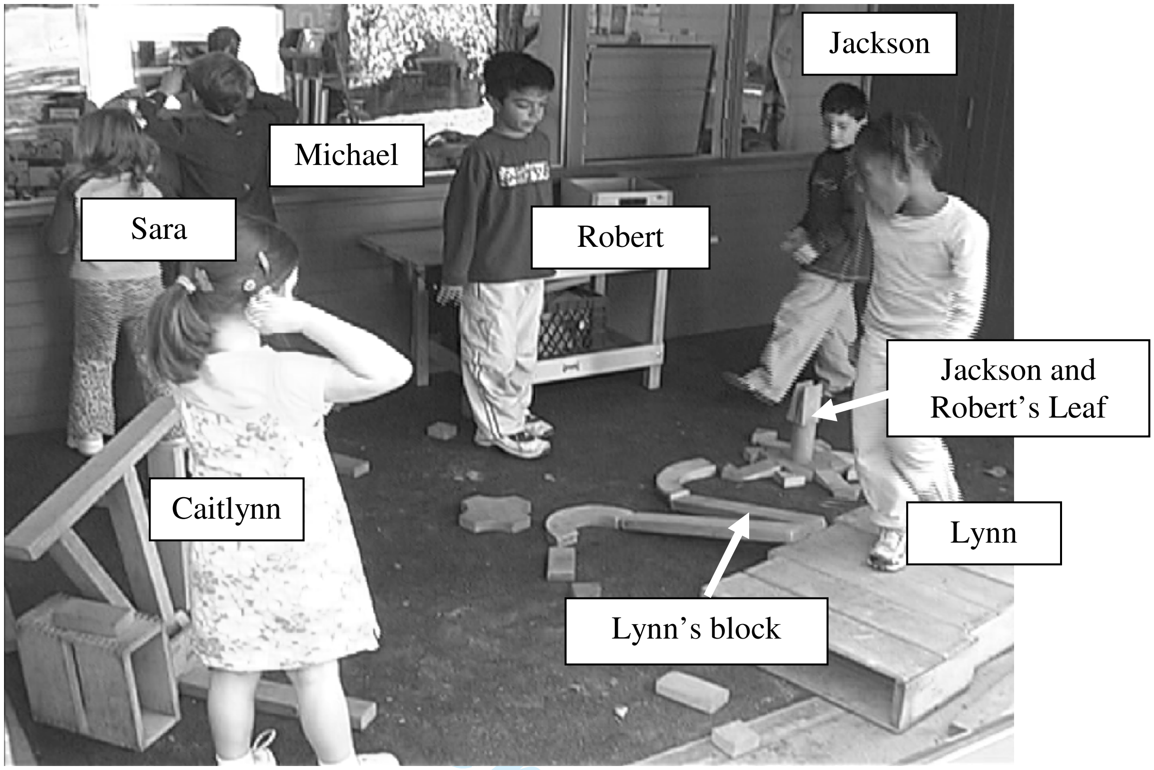

Figure 2: The Students Building with Blocks

Figure 3: Michael Presents the Results of the Vote While Lynn Crouches Below