Gathering Evidence of Scientific Argumentation Practices: From Pre-Kindergarten to High School

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Abstract: The purpose of this symposium is to explore students’ scientific argumentation practices in relation to the recently released Framework for K-12 Science Education (NRC, 2011) in the United States. We will present data from four research efforts on pre-kindergarten, upper elementary school, and high school students’ science learning in classroom settings, followed by a reflective presentation by a discussant. Given that our work spans multiple grade levels of formal school instruction, we will discuss our observations across these groups of students while mapping to the goals and suggested progression of argumentation practices described in the NRC framework.

Symposium Overview
The purpose of this symposium is to explore students’ scientific argumentation practices in relation to the recently released Framework for K-12 Science Education (NRC, 2011) in the United States. We will present data from four research efforts on pre-kindergarten, upper elementary school, and high school students’ science learning in classroom settings, followed by a reflective presentation by a discussant. Given that our work spans multiple grade levels of formal school instruction, we will discuss our observations across these groups of students while mapping to the goals and suggested progression of argumentation practices described in the NRC framework.

Argumentation is recognized as a necessary and central component of science, and an understanding of scientific argumentation is essential for all people – for scientists to conduct their work and for citizens to productively engage with everyday topics such as the environment or personal health. The NRC framework (2011) specifically highlights the importance of scientific practices in addition to crosscutting concepts and disciplinary core ideas, in quality science education. Indeed, this aligns with trends in science education and the emphasis on moving away from teaching science as purely factual knowledge and instead incorporating scientific discourse, explanations, and argumentation (NRC, 2007, 2009; AAAS, 1989, 1993). Not only does the overall emphasis on scientific discourse better align with actual disciplinary practices of professional scientists (e.g., Bell, 2004; Edelson & Reiser, 2006; Newton, Driver, & Osborne, 1999), but opportunities to engage in argumentation in the science classroom have been shown to increase students’ conceptual understanding and reasoning skills (e.g., Mercer, Dawes, Wegerif & Sams, 2004).

Despite the general consensus on the importance of understanding how to argue scientifically, it is still often missing or ineffectively utilized in typical science instruction across grade levels. The research presentations in this symposium highlight four curricular design efforts to support students’ capacities to engage in scientific reasoning and argumentation while also integrating their personal experiences, interests, and relevant topics in their community to increase their knowledge of and participation in science. Our goals for the symposium are to examine how students engage in scientific argumentation within these units and add to the discussion of the progression of scientific argumentation (Berland & McNeill, 2010; NRC, 2011) practices across pre-kindergarten through high school science education.

The first paper examines the developing abilities of pre-kindergarten children, ages 4-5 years, to engage in scientific argumentation in classroom science discussions. Although these young children do not systematically use evidence and construct complete arguments every time, these data show that they are capable of using data to support their claims. Often the students draw upon their everyday experiences and knowledge of the natural world, but they also reference shared classroom experiences or artifacts as they make their claims.

The next two papers focus on fifth grade students’ participation in re-designed science curricular units. One paper looks at how 5th Grade students in a science classroom engage in collaborative debate on a controversial issue on Triclosan. The other paper compares argumentation across three curricular contexts. One
unit is a traditional, teacher-directed unit. The other two units, of our own design, feature student agency and student-directed investigations. Argumentation varies widely across contexts with differing amounts of agency.

The last paper examines high school students’ argumentative reasoning during hypothesis development and testing with a real dataset in a refined science curriculum designed for engaging students in an authentic practice of genomic and epidemiological research. The authors analyzed student conversations during their investigations. They found that argumentative reasoning emerges during both hypothesis development and statistical analysis. Students did frequently articulate logical relationships among claim, evidence, and reasoning, and they worked to develop alternative explanations when they encountered results contradictory to their original hypothesis. However, they also found such reasoning is limited during causal inference. The authors developed a hypothesis that both students and teachers may have developed a “singular” view of scientific method for causal reasoning as a reflection of the existing science curriculum, and it might interfere when they learn other scientific methods.

We intentionally present data from across pre-kindergarten through high school curricular enactments to advance conversations about the development of and expectations for school aged youths’ argumentation practices. Our discussant, Philip Bell, will provide reflective commentary on the presentations.

**Paper 1: Supporting Pre-Kindergarten Students’ Emergent Scientific Argumentation Practices (Tiffany R. Lee)**

Views on science education have undergone significant changes in the twentieth century. Science has traditionally been taught as a well-defined process using the scientific method (hypothesis, experimentation, control of variables, etc) with theories, concepts and vocabulary to memorize. In the last 50 years, science education reforms have worked to impart more accurate accounts of scientific ideas, practices, and reasoning skills to schoolchildren. In particular, the recently released NRC Framework for K-12 Science Education (2011) has explicitly called for increased attention to students’ understanding of scientific practices. In this paper, we identify instances of pre-kindergarten students engaging in scientific argumentation during classroom science instruction and provide evidence of the progression of argumentation practices.

Osborne (2010) suggests that the nature student participation in reasoning and argumentation is complex, dependent upon their existing domain-specific knowledge and their reasoning capabilities at a given age. For very young children, science instruction is often limited to direct observations and hands-on activities, with the assumption that they are not yet capable of abstract thinking and reasoning. Much of the existing early science curricula and teaching approaches are based upon an overextension of Piaget’s conjecture that young children are concrete, simplistic thinkers, resulting in unnecessary and oftentimes inappropriate constraints on young children’s learning (Metz, 1995).

The research effort described in this paper presupposes that young children are capable science learners and should be provided with opportunities to support their developing science knowledge and skills (cf. Brown, Campione, Metz, & Ash, 1997; Eshach & Fried, 2005) and builds upon recent research that demonstrates young children’s developing knowledge and experiences with science (Lee, 2010) and their abilities to engage in extended discourse and argumentation (e.g., Lee, 2011; Corsaro, 2003; Gallas, 1995). The overarching goals of the curricular design are to leverage young children’s existing knowledge and interests about the natural world and engage them in the processes of science. We draw upon theory about how people learn, particularly in relation to engaging learners’ interests and preconceptions (NRC, 2000; Vygotsky’s (1978) notion that knowledge is co-constructed by people and that children’s learning is optimally supported by identifying and leveraging zones of proximal development; and applications of Brown and Campione’s (1994) work on creating classroom communities of learners. This paper focuses specifically on pre-kindergarten students’ engagement in scientific argumentation and their use of everyday experiences and knowledge to support their claims. We will show the emergent argumentation practices of these young students and discuss how the classroom teachers facilitated these opportunities for argumentation.

**Methods**

The data presented in this analysis are part of a year-long curricular intervention in two half-day pre-kindergarten classrooms in the Northwest region of the United States. Each of the pre-kindergarten classrooms comprised of 12-15 students (ages 4-5 years) one lead teacher, and one assistant teacher. Researchers worked with the teaching team to develop weekly science lessons that emphasized student-led discourse, argumentation, and connections to their existing knowledge of the natural world. Lessons included exploration of artifacts brought into the classroom (e.g., live animals, plants, fossils), observations of the outdoors, and questions to spark student discussion, and typically lasted between 30 to 60 minutes each. To preserve the authenticity of student-generated topics of study, the lessons were designed throughout the school year and built upon students’ interests and questions. Data sources included 1) video recordings of the weekly science lessons, 2) fieldnotes from classroom observations and teacher interviews, 3) digital photographs of classroom activities, 4) artifacts
such as student-made drawings and writing samples, materials used for instruction, etc., 5) teacher interviews to reflect on science instruction throughout the year, and 6) parent surveys about students’ out-of-school activities.

**Analysis and Findings**

Video data of class discussions were analyzed for examples of scientific argumentation between two or more students. As hypothesized, questions that tapped into children’s common experiences but did not have obvious factual answers allowed for extended discourse and argumentation. One unit at the beginning of the school year focused on living vs. non-living things. We began by asking the students what it means to be alive and having them identify characteristics of living things. Students offered ideas from their existing knowledge of the living world: it moves, it talks, it eats, etc. Teachers then asked questions to challenge students’ ideas. One question, “Are plants alive?” prompted an extended discussion between the students – do plants make noise and do they eat? In this discussion, we observed students making references to their existing knowledge of plants (e.g., knowing that plants cannot make noises or move on their own), and then trying to reconcile these ideas to support the argument that plants are living things.

In another lesson, students are presented with two hamsters – one real hamster and one toy hamster that runs on a wheel. The students are asked to decide whether each hamster is alive based on the qualities they have identified for living things. Students easily agree that the real hamster is alive – it moves, breathes, eats, and maybe it can make a noise. They also know that living things can reproduce (often talked about as “making more” or “having babies”), and they guess that the real hamster can do this. The toy hamster is puzzling at first: several students claim that it could be alive because it moves on its own. Upon closer investigation, one student notices that it has wheels instead of feet and guesses that it uses a battery to move. After more discussion, they agree that the toy hamster is not alive.

Throughout the data, we see that students are often quick to give an opinion in response to the teacher’s questions. When the teacher follows up by asking for a reason behind that opinion or encourages other students to voice a differing opinion, the students are given opportunities to explain their thinking. In these instances, we see that the pre-kindergarten students often support their claims with evidence from their out-of-school experiences or shared classroom activities.

**Discussion**

Findings from this work show that even very young children are able to engage in scientific argumentation and the development of these practices needs to be supported in science instruction. In these data, pre-kindergarten students readily engage in extended discourse and argumentation when presented with topics that relate to their early experiences with the natural world and encouraged by the teacher to give opinions and agree or disagree with their peers. Although these students do not systematically use evidence to support their claims or necessarily construct thorough arguments each time, they easily leverage their experiences and knowledge to support their claims. Increased opportunities for young children to engage in argumentation practices will likely improve their abilities to successfully use data to support their claims and allow them to become more proficient in their argumentation practices over time. Further research is being conducted to document the range of young children’s abilities, particularly as they relate to how children engage in scientific discourse and argumentation and how they make connections to their everyday experiences. In addition, we seek to better understand the role of the teacher in creating an environment that supports this kind of discourse and science exploration. As a result of these and other related findings about young children’s reasoning abilities, we argue that the goals and approaches for science education need to be revised to support the development of early scientific skills and prepare children for future success in science.

**Paper 2: Achieving Coordination in Collaborative Debate (Giovanna Scalone)**

Teaching students to argue and collaboratively engage in discourse are central features of inquiry in the natural sciences (Bell, 2004). We draw on Bell’s framing of argumentation and debate in science as the exploration of a theoretical controversy involving the coordination of evidence with theoretical ideas (p. 138). When students engage in collaborative argumentation, they are “arguing to learn”. This implies that students are collaboratively exploring solutions dialogically (Andriessen, 2006). From a Vygotskian perspective, it is through language that we come to know things, and transform knowledge into actions, objects, and other symbol systems. Argument is a form of discourse, which according to Kuhn (1991) requires one to not only think in a metacognitive and metalinguistic framework, but to also place one’s ideas in the planes of the possible, the probable, and the disputable (Pierut-Le Bonniec & Valette, 1991).

Elementary school students are rarely asked to participate in collaborative debate and discussion of controversial topics in science education (Levinson & Turner, 2001). As a result, in classroom debate students find difficulties in anticipating objections in their own arguments as well as in the arguments of others (Reznitskaya et al., 2001). This issue also arises because students have difficulties in understanding the
evidentiary nature of scientific arguments and the social dimensions of science (Bell, 2004; Kuhn, 1993; Driver et al., 1996).

In this paper, we discuss the findings of two elementary school science debates on ‘Should hand sanitizers be banned?’ Perspective taking is essential in science where students come to understand the standpoints of various stakeholders associated with the controversy around triclosan. In addition, we wanted students to move beyond their epistemological naiveté and consider a theory as well as evidence and its bearing on a theory (Kuhn, 1991). Helping students to think about their own thinking will help them learn how to evaluate evidence. Finally, it is possible that helping students weigh different forms of evidence enables them to formulate and reformulate ideas, which, in turn, fosters conceptual change (Koslowski, 1996). In this paper we ask: How do elementary school students in science achieve coordination in debate?

Methods & Data Sources
This study took place in two fifth grade science classrooms at Granite Elementary School in an urban neighborhood. There were five iterations of the Micros & Me curriculum, in which the content was framed around microbiology and health; and students were given choice and agency to document community-relevant health topics; design fair tests; and choose a personally-relevant, related topic and conduct research. We report on the findings from the fifth iteration, specifically on a debate, ‘Hand-sanitizers should be banned’. We helped student’s structure their debates by drawing on Bell’s (2004) framing of argumentation and debate. We think of argument as a product, which includes claims, evidence, and reasoning; and we think of argumentation as the process of assembling these components in order to make one’s case. Students debated on whether hand sanitizers that contain Triclosan (an antibacterial, antifungal agent used in consumer products, such as hand sanitizer, toothpaste, etc.) should be used since it affects the microorganisms in the water.

In Fall of 2010, participants included 29 consented fifth graders (all between 10 and 11 years old) and two teachers, Ms. Jones and Mr. A. Ethnographic techniques were incorporated into the design to leverage students’ everyday expertise. The data sources came from participant observation using field notes and digital photography of instruction in the science classrooms, video recording, student illustrations, and students’ notebooks.

Findings
By following Bell’s (2004) framing of argumentation and debate within student discourse as well as verbal and nonverbal (cf. Lemke, 1998) argument, in this paper we endeavor to understand how students coordinate their evidence in classroom debate. Preliminary findings reveal that as students engage in different modes of evidence to support their position in the triclosan debate, some were faced with difficulties separating theory and evidence, producing pseudoevidence (Kuhn, 1991). Other students made good evidence-based arguments, however their arguments where disassociated with the counterarguments.

Discussion
The findings have implications for how we can help students not only think about perspective taking in science, but also scaffold their thinking in ways that can help them critically evaluate arguments for the opposing position and make every argument associated with a counterargument. Overall, this contributes to helping students understand how scientists work by having them engage in critique and evaluation. Consequently, students come to understand that science is a body of knowledge that is rooted in evidence-based argumentation (NRC, 2011).

Paper 3: Student Agency and Argumentation Across Curricular Contexts (Kari Shutt, Nancy Vye, & John Bransford)
An important goal for science education is to provide students with the opportunity to engage in authentic science practices (National Research Council, 1996, 2011). Argumentation is a key component of scientific discourse and plays a central role in the construction of knowledge. It is the means by which the scientific community reaches consensus, and is therefore a crucial scientific practice (NRC, 2007, 2011).

In this study, we compare argumentation across three different curricular contexts that differ in terms of their level of student agency. Each unit is taught to 5th grade students over the span of 12 weeks. One unit, the FOSS Environments unit, is a kit-based unit that features discrete, teacher-directed investigations. The other two units, the Isopod Habitat Challenge and My Skokomish River Challenge, were designed by our research team. The cornerstones of the latter units are student agency and student-directed collaborative investigations related to an overarching problem (Vye et al., 1998).

Methods
The study took place in a mid-sized suburban school district. We selected one teacher and class from each curricular context as cases for consideration. Within each class, we selected one small group of students to
follow closely. Each of the three units involves a series of investigation cycles. We chose to examine an investigation cycle that took place midway through the units. We focused our attention on the selection of the research question and the experimental design process. The primary data source was naturalistic video. Videos were transcribed for analysis, and episodes were coded using an adaptation of Chin and Osborne’s (2010) argumentation coding scheme.

Findings

Case 1: FOSS Environments (Comparison)
In the FOSS-Environments unit (Delta Education (Firm), Lawrence Hall of Science, & University of California Berkeley, 2000), students undertake a series of life science investigations. In most instances, students investigate questions that are determined by the teacher, and students typically follow prescribed procedures to investigate those questions.

In this investigation cycle, Ms. Stark gave her students the investigative question at the start of the class session, and asked students to brainstorm ways that they might conduct the investigation.

George: Well if it’s like too cold or something it [the isopod] could roll up into a ball or just stay very still.
Eileen: I think it rolls up into a ball when it's scared because um
George: Or when it just doesn't like the climate.

Student interaction was limited for the Comparison students, and there was minimal evidence of argumentation, with only one weak rebuttal offered during the conversation.

Case 2: Isopod Habitat Challenge (IHC)
The Isopod Habitat Challenge addressed the same learning objectives as the FOSS Environments unit, but in the redesigned unit, the IHC, small groups of students conducted sustained, original inquiry in which they determine what and how to design a classroom habitat for isopods. Ms. Atwell began this investigation cycle with a 90 minute, student-led discussion about researchable questions. She interjected open-ended questions periodically to move the discussion forward. After this discussion, Ms. Atwell released the students to generate a question in their small groups. The students considered seven possible questions before settling on their choice. Design of the procedure flowed naturally from the conversation about investigative questions, with students designing their experiment as they debated the merits of the possible questions.

In total, IHC students spent 59 minutes in small group conversation around design issues. The IHC students offered more new ideas about investigative questions and experimental design than students in the FOSS, and they demonstrated more evidence of argumentation around those ideas. This included an emerging ability to identify weaknesses in claims.

Lisa: Do isopods drink water?
John: You can't find that out. We can't find that out.
Jessi: All organisms need water.
Lisa: Nu-uh. They could eat like- they could eat the- they eat the carrots that has moisture in them as their water.
John: Really, you can't tell if they're drinking really.
Lisa: You could. Really, you could. You put a certain amount of water in a little cup or something and measure it and then you see if later on there's a little less amount.
John: Well it would be so tiny you could barely find it.

Case 3: My Skokomish River Challenge (MSRC)
MSRC is an earth science unit based on similar design principles to the IHC. It is challenge-based and features opportunities for sustained inquiry, revision of ideas, and student agency. It also features a number of student-led investigations.

To set up the investigative question selection, Ms. Donovan told students what experiments they might do and how they might go about conducting them. When given the opportunity to select their question in their small group, one student simply stated a question from the list. For the procedure, Ms. Donovan gave students a “fill-in-the-blank” procedure sheet. Students inserted their variables on the blank spaces; the remainder of the procedure was provided for them. There was no discussion of the procedure in the small group. Despite the fact that the unit was designed for student agency--where students would generate questions to investigate and design ways to investigate these questions--that agency was not offered to them in this investigation cycle. These activities were highly-constrained and structured by the teacher. Only 14 minutes were provided for small group conversation. This particular group did not choose to interact during that time, and thus, there was no evidence of argumentation.
Discussion
Findings from the IHC unit suggest that authentic, “agentive” science inquiry can provide a rich context for engaging students in productive argumentation. However, we saw widely different outcomes in the IHC and the MSRC, despite their common design principles. Curriculum can create an environment that fosters productive argumentation, but particular pedagogical moves are needed to support this practice. Positioning students as knowledgeable and capable of independent inquiry, for example, by asking open-ended questions and encouraging student-to-student interaction and decision-making, appear to foster agency and productive argumentation.

Paper 4: High School Students’ Argumentative Reasoning During Hypothesis Development and Testing In Epidemiological Analysis (Hiroki Oura, Katie Van Horne, Andrew Shouse, and Maureen Munn, Randy Knuth)

Introduction
Developing a scientific argument can be seen as marshaling relevant evidence and justifying an explanation relative to other alternative explanations for particular observations or phenomena (Osborne & Patterson, 2011). As a basic form for instruction, students should develop an argument with a set of claim, evidence, and reasoning, and they also need to hedge their argument by articulating the limitations and possible rebuttals (Toulmin, 1958; McNeill & Krajcik, 2012). The key for meaningful classroom practice is to provide the appropriate contexts in which students may reach multiple reasonable explanations, for instance, by analyzing a real dataset (instructional context), by supporting explanations with relevant evidence (argumentative product), and by defending their explanations and questioning explanations from others (argumentative process) (Berland & McNeill, 2010).

The authors have refined an existing curriculum aimed at engaging students in an authentic practice of genomic and epidemiological research (Munn et al., 2010) and developed a set of scaffolds in collaboration with genome scientists in a three-year project. The goal of this design-based research is to engage students in authentic data analysis with a real dataset in which they develop arguments for factors that increase a person’s risk of becoming a regular smoker. Smoking is a multifactorial trait, and various environmental and physiological (or genetic) factors contribute to its initiation and the difficulty in quitting (cessation). The dataset is from a real case control study of nearly 300 adult smokers and non-smokers and includes items from the research survey completed by subjects and limited genotyping on their DNA. Students develop explanatory hypotheses by defining the exposures and non-exposures for selected survey items as candidate factors. Students test their hypotheses by calculating a significance test for association and determining causal inference by applying a set of criteria used by epidemiologists. For each test (limited to only a few), students estimate the odds ratio as the magnitude of the difference in likelihood for the exposure between regular smokers (cases) and those who tried smoking but did not continue (controls), and evaluate the significance with the 95% confidence interval. Once students identify the association by the statistical evidence and their reasoning, they may make causal inference by scrutinizing the degree to which their results meet a set of criteria for causality such as the strength of association, temporal sequence, consistency with other studies, and lack of confounding factor (Bradford Hill, 1965).

Method
In this study, we examined high school students’ argumentative reasoning as they conduct hypothesis development and testing during our first-year implementation. Our data include video- and audio- recordings during data analysis and associated field notes from 13 high school student groups (2 to 4 students per group) in urban or suburban public schools or a local summer program. All teachers in the classrooms had participated in a training workshop in which they learned basic concepts in the curriculum and practiced data analysis with their own investigations. In the classrooms, students conducted their investigations after learning basic concepts related to the model of smoking, case control study, and evaluation with the odds ratio and confidence interval, mostly in a lecture format. We analyzed student conversations during their data analysis and evaluated their argumentative reasoning using the instructional model articulated by McNeill & Krajcik (2012). Due to the variability in the lengths and situations of the recordings among the participating classrooms, we focus on and report noteworthy themes on students’ typical patterns and performance followed by our discussion along with the learning progression and instructional concerns.

Findings
Our analyses indicate that argumentative reasoning can emerge during hypothesis development based on informal evidence such as students’ beliefs, experience, and observations. Students often developed their hypothesis as they identified a survey item related to their overarching hypothesis and justified their hypothesis to the item by drawing on such informal evidence. As an ideal case, for instance, when one student in a group
was developing a test to see if having a close relationship with parents who smoke can increase a risk of smoking, another student proposed an alternative hypothesis that people might not smoke because their parents smoke by drawing on her father’s case (they called it “rebelling”). They decided to test this hypothesis and found that the odds ratio was insignificant; they concluded the hypothesis was not supported, though they each appeared to maintain their belief in their own hypothesis after testing.

During statistical analysis, students frequently consider and articulate logical relationships among claim, evidence, and reasoning when they evaluate the association from the odds ratio and confidence interval. Most groups appropriately evaluated the significance of the association from the confidence interval by reasoning in a way such as “one is outside the interval, so there is association” (the null is one). Their reasoning seemed to become more active particularly when they encountered results contradictory to their original hypothesis, and students worked to develop an alternative explanation fitting the results.

Lastly, we found that argumentative reasoning rarely emerged during discussions of causal inference, and when students did talk about the criteria for causality, they focused on the strength of association. This is likely due to the curriculum structure, as its main focus is placed on how to appropriately interpret the odds ratio and confidence interval rather than asking students to evaluate and construct causal inferences. Yet, these criteria were explicitly shown in a table in the curriculum and teachers had practiced the causal reasoning in the prior training workshop. We identified some cases that both students and teachers seemed to reject the idea that they could make causal inference because the case control study is not “controlled” (according to their explanation of characteristics of a study needed to infer cause). In reality, however, epidemiologists often make causal inferences based on evidence for association from observational studies due to several ethical and practical reasons (Koepsell & Weiss, 2003). We could hypothesize that some teachers and students may hold a “singular” view of scientific method for causal reasoning (Lederman et al., 2002), and it might interfere when they learn other methods, since the randomized and manipulated control experiments are the predominant form of hypothesis testing in today’s K-12 science curricula and standards (Windschitl et al., 2007). Although it is hard to generalize the issue within the present study, this “epistemological” aspect of argumentative reasoning is worth further investigation to the existing literature in our future works.

References


