The Role of Explanations in Learning

Organizers: Lauren Barth-Cohen, Jennifer Chiu, Beat Schwendimann,
University of California, Berkeley, Berkeley CA, 94720.
Email: lbarth@berkeley.edu, jenchiu@berkeley.edu, bschwendimann@berkeley.edu

Abstract: This poster session brings together six perspectives on the role of explanations in learning. Each poster presents recent empirical and/or theoretical findings that address how, when or why explaining is beneficial for learning. This session will highlight the similarities and differences among how the term *explanation* is used in cognitive science, psychology, and science education with the aim of moving the field towards a better understanding of how explanations can support learning. By bringing together these researchers we aim to encourage communication around what constitutes an explanation and how the researchers from different communities are addressing similar issues, such as the nature of teacher's explanations, student's explanations, expert's explanations, and self-explanations and their role in learning.

Introduction

Explaining a phenomenon or why it occurs is viewed as a central element of science. Similarly, learning from scientific explanations is seen as an important goal of science education (National Research Council, 2007). A multi-disciplinary line of research from the science education community, cognitive psychology community and learning sciences community is interested in understanding the role of explanations in learning. In this symposium we bring together these different perspectives to highlight current research surrounding how and why explanations benefit learning, and identify similarities and differences among these approaches as to what constitutes an *explanation.*

Rationale

There is a great deal of evidence that the process of generating explanations can be beneficial to learning (e.g. Chi et al. 1994), and there is some evidence that explaining can promote conceptual change in young children (Amsterlaw & Wellman, 2006; Chi, 2000), but we do not know in detail how explaining helps learning (Lombrozo, 2006). Specifically we do not know what types of explanations are more or less beneficial for learning, what explanations look like in different disciplines, and what other factors might influence if and how explaining supports learning. This symposium has two main foci. First, we explore the relationship between the explanation and the type of learning being sought after, and second, we aim to identify variations within the term *explanation.*

The researchers in this symposium address the role of explanations in learning in a variety of ways. For example, one poster investigates how teachers' pedagogical content knowledge of scientific explanation and argumentation changes while they learn new practices in professional development. Another poster investigates the relative impact of explanation, exploration and observation on children's learning of underlying causal relationships and mechanisms. Across these posters there are differences in the populations being studied and how researchers operationalize *learning;* however, the common focus on explanations in learning will enable productive communication between the researchers from different perspectives, and should support a fruitful discussion with audience members.

Within the learning sciences community the term *explanation* is used in a variety of ways. The second goal of this symposium is to support a more precise understanding of the similarities and differences among these complementary perspectives. For example, one presenter views explanations as the "big ideas" or conceptual frameworks that are socially accepted by the professional science community, and aims to help students develop these kinds of complex understandings. Other posters view constructing explanations as a critical practice within the scientific community and present research that explores how both students and teachers develop epistemic understanding of scientific explanations. A poster from the cognitive science perspective builds upon the philosophy of science to view explaining as a constraint on learning that facilitates the interpretation of observations in terms of unifying patterns. One poster puts forth a comprehensive taxonomy of the possible components of a scientific explanation that can be used to characterize and better understand various types of novice and expert explanations (for a complete summary of posters, see Table 1). By bringing these perspectives together, we aim to encourage greater communication across fields and further our collective understanding of the nature and utility of explanations.

Table 1. Summaries of research focus, participants, and contributions for each poster.

Presenter	**Focus**	**Participants**	**Research Contribution**
Legare & Lombrozo	Compares self-explanation to exploration and attention	36 children aged 5 and 6	Explanations promote learning about mechanisms, but may have less benefit for memory of individual features
McNeill & Knight	Explores changes in teachers' pedagogical knowledge of scientific explanation and argumentation	24 grade 5-8 teachers	Teachers need to develop an awareness of the nature and importance of scientific explanation and argumentation as a key part of their pedagogical content knowledge
Sandoval et al.	Investigates relative influence of conceptual and epistemic understanding on biology students' ability to construct explanations	400 grade 6 and 7 students	Will clarify the degree to which conceptual knowledge and the understanding of epistemic requirements of a scientific explanation promotes learning
Williams & Lombrozo	Explores the effect of explanation on the ability to generalize to novel contexts	University undergraduates	Explaining constrains learners to interpret what they are learning in terms of general unifying patterns, driving the discovery of subtle generalizations that support transfer to novel problems and situations
White et al.	Presents a comprehensive taxonomy for the possible components of scientific explanations	Novice and expert explanations in physical and life science	Ability to characterize learners' existing and developing explanatory capabilities, as well as to characterize expert explanations that are generated by teachers and scientists
Zembal-Saul	Investigates how teachers' preparational experiences mediate their learning to teach science	Preservice K-5 teachers	Preservice teachers were able to adopt an increasing emphasis on evidence, explanation, and science content in addition to classroom discourse

Explanation as a guide to learning

Cristine Legare, Department of Psychology, University of Texas at Austin, 1 University Station #A8000, Seay Building 5.216, Austin, TX 78712-018. Email: legare@psy.utexas.edu
Tania Lombrozo, Department of Psychology, University of California, Berkeley, Berkeley, CA 94720. Email: lombrozo@berkeley.edu

Although prior research with adolescents and adults has demonstrated that self-explanation benefits learning (Chi et al., 1994), little is known about the effect of self-explanation on learning in young children (but see Crowley & Siegler, 1999). The objective of the present study is to investigate the relationship between explanation and learning, and most importantly, to measure learning more directly by comparing self-explanation to other potential learning mechanisms such as exploration and attention. Does constructing a causal explanation benefit learning more than exploration or simple observation?

In order to test the differential effects of explanation on learning and to explore the relationship between explanation and learning experimentally we have constructed a novel problem-solving task that consists of a machine with five interlocking gears (see figure 1). When the gears are connected in the correct way a crank operates the machine and makes a fan turn. The three middle gears have peripheral pieces attached to them, which are used to differentially assess children's memory versus their understanding of the functional mechanism of the machine. Prior to participating in the test conditions children observe the intact machine. Using a between-subjects design, children will participate in one of four conditions: a control condition in which children attend to the machine but do not explain or explore (*attend condition*), exploration without constructing an explanation (*explore condition*), exploration after constructing an explanation (*explain plus explore condition*), and explanation without exploration (*explain condition*).

Figure 1. Gear machine. Shown with missing part and five candidate parts.

Following the experimental manipulation, children participate in three additional tasks. Two of the tasks are learning measures (presented first) followed by one procedural knowledge measure in which children are asked to reconstruct the machine. In each of the learning tasks the intact machine is presented to the child with one gear missing. In the *functional relationship learning task*, five candidate parts are presented to the child, none of which are identical to the missing part. The choices are: the correct size and shape but different color, a part of the correct shape but incorrect size, a part of the correct size but incorrect shape, a peripheral part they have seen before but is not the correct shape, and a distracter part. In the *memory learning task* another 5 candidate parts are presented to the child to assess the child's memory for the exact missing piece. All 5 pieces are the correct size and shape but only one is the same color as the missing piece. In each task the child is asked to select the part that will make the machine work. After completion of the learning tasks the machine is taken apart. All of the gears are removed from the base, and the peripheral parts are removed from the 3 middle gears. Participants are asked to reconstruct the machine in exactly the same way they saw it before and make it work.

Preliminary analyses with 32 children ages 5 to 6, in two key conditions, indicate that engaging in explanation leads to greater success in recreating the functional relationships within the machine (14 of 16 children) than simply attending to the machine (6 out of 16 children). Conversely, children who attend to the machine but do not engage in explanation are more successful in correctly matching peripheral parts to individual gears. Preliminary analyses also support a benefit for explaining in the learning measures. For the functional relationship learning measure only, children were more likely to select the correct functional part after engaging in explanation than merely attending, $t(31)=2.45$, $p<.05$. This suggests that explanation promotes learning about underlying causal relationships and mechanisms, but may have less of a benefit for memory of individual features. In sum, our data provide preliminary evidence that the process of constructing an explanation differentially promotes causal learning and suggest that explanation plays a role in young children's learning by highlighting functional and causal relationships and helping them integrate elements along a causal pathway.

The role of explanation in discovery and generalization: evidence from category learning

Joseph Williams & Tania Lombrozo, Department of Psychology, University of California, Berkeley
Email: joseph_williams@berkeley.edu, lombrozo@berkeley.edu

A convergence of theory and data in education research, cognitive development, and cognitive psychology provides evidence for the significant role explanation plays in learning. Research in education (Chi et al, 1994) and cognitive development (Siegler, 2002) suggests that generating explanations drives the acquisition of knowledge that is retained in the long term and produces a depth of understanding that gives learners the basis to transfer and generalize to new situations. Explanation also plays a key role in theories of how conceptual knowledge is represented (Murphy & Medin, 1985) and explaining can even promote conceptual change in young children (Amsterlaw & Wellman, 2006).

Although explanation's effect on generalization is well-established in real-world contexts, less is known about the mechanisms that underlie explanation's privileged effect on generalization, possibly because of the complexity of these domains. We used three experiments on how people learn artificial categories in order to rigorously test a specific hypothesis: that explaining drives people to interpret what they are learning in terms of unifying patterns, which drives the discovery of underlying regularities that provide the basis to generalize. This hypothesis is motivated by theories in philosophy of science about what properties explanations possess, which we use to address a concern of this symposium: characterizing what explanations are in order to understand why they help learning.

Subsumption theories propose that explanations show how what is to be explained is an instance of a general pattern or regularity. *Unification* theories propose that explanations are better to the extent they account for diverse observations under a single pattern. These theories predict the privileged relationship between explanation and generalization: trying to construct explanations that satisfy the properties of subsumption and unification constrains learning, by driving learners to reason and form beliefs that allow them to interpret what they are learning in terms of unifying patterns. This drives the discovery of regularities that are present, producing exactly the kind of knowledge that supports generalization to novel contexts.

The basic design examined people's learning about a category when explaining, compared to the control conditions of describing, thinking aloud, and free study. Participants learned about two categories of alien robots, 'glorps' and 'drents', from 8 training items. The items' features (color, body shape, foot shape) supported two different generalizations about category membership: (1) the '75% rule', as 3 glorps and 1 drent had square bodies while 3 drents and 1 glorp had round bodies, or (2), the subtle '100% rule', as all glorps had pointy feet and all drents had flat feet- though each robot's feet were a unique shape. Participants were given a sheet displaying the 8 robots with category labels. The robots were also shown onscreen, and participants either *explained* why robots might belong to a category, *described* robots, *thought out loud*, or were allowed to engage in *free study*. Following study, the sheet was removed and participants categorized new robots that pitted the 75% rule against the 100% rule, received a memory test for the studied robots, and reported perceived differences between glorps and drents.

Relative to the control conditions of describing, thinking aloud, and free study, explaining promoted discovery of the subtle 100% foot rule, which supported generalization of category membership to new robots. Explaining exerted constraints that drove people to discover a regularity that provided a unified explanation for the membership of *all* items, as predicted by subsumption and unification accounts. Despite explanation's beneficial effects on discovery and generalization, describing resulted in better memory for item details and provided insights into what kind of information explaining is useful for learning. A coding of explanations and descriptions suggested that explaining might drive the generation of abstract hypotheses. Experiment 2 further suggested that explaining anomalies plays a role in promoting discovery and rejecting incorrect beliefs, compared to focusing attention on those anomalies.

By testing the predictions of theories of explanation, the experiments give insight into *why* and *how* explaining promotes generalization. They further suggest intriguing possibilities for future research: whether the subsumption and unification constraints of explanation may drive 'illusory' discovery. Speculatively, errors such as forming 'conspiracy theories' or stereotypes could be due to explaining small or unrepresentative samples of observations, which drives the induction of spurious patterns.

Teachers' Pedagogical Content Knowledge of Students' Science Writing and Talk

Katherine L. McNeill, Amanda M. Knight, Boston College, Chestnut Hill, MA
Email: kmcneill@bc.edu, amanda.knight.1@bc.edu

The practice of science is not the uncovering of truth; rather, science is fundamentally about a community of scientists developing, debating and refining explanations through the use of evidence (Duschl, Schweingruber & Shouse, 2007). Implicit in this essential process are the scientific practices of explanation and argumentation. Developing an explanation in science focuses on how or why natural phenomena occur (Nagel, 1961). Constructing an argument includes both a social meaning, which focuses on debate between multiple individuals, and an individual meaning, which focuses on the argument product as a claim justified with evidence, warrants, and backing (Jiménez-Aleixandre & Erduran, 2008). Our goal is to combine these two practices to help teachers support their students in developing explanations about phenomena in which they debate and justify their claims with appropriate evidence and reasoning (McNeill, Lizotte, Krajcik & Marx, 2006).

Although recent research suggests the importance of these practices, teachers rarely engage students in explanation and argumentation in their own science classrooms (Newton, Driver, & Osborne, 1999). One reason for why this rarely occurs is teachers' lack of pedagogical strategies to support students in this complex practice (Zohar, 2008). Simon and her colleagues (2006) argue that for teachers to change their classroom practice they need professional development experiences that focus on teachers' existing understanding of evidence, explanation, and argumentation. We cannot expect teachers to incorporate explanation and argumentation into their classrooms if they do not have stronger understandings of these scientific inquiry practices (Zembal-Saul, 2009). Teachers require pedagogical content knowledge (PCK) for scientific inquiry practices or knowledge of how to teach students to engage in scientific inquiry practices (Davis & Krajcik, 2005). Yet there is currently little research in the field focused on teachers' understandings or teacher education in this area of scientific explanation and argumentation (Zohar, 2008). Consequently, our research looks to address the following research questions: 1) How does teachers' pedagogical content knowledge for scientific explanation and argumentation change while participating in professional development focused on this topic?

This study took place with twenty-four grade 5-8 teachers in a large urban district in New England. The teachers participated in a series of workshops over the span of four months. Multiple data sources were collected to evaluate teachers' initial pedagogical content knowledge as well as to determine whether or not that knowledge changed. Data sources included: pre and post surveys, videotapes of the professional development workshops, artifacts produced by the teachers, and samples of strong and weak student writing that the teachers brought to the workshops. The coding schemes for the data sources were developed from the theoretical framework and iterative analyses of the data (Miles & Huberman, 1994). Data sources were coded by two independent raters and all disagreements were resolved through discussion.

Preliminary analysis of the data suggests that the majority of teachers began the professional development with different understandings of what counts as high quality student writing compared to high quality student talk. On the pre-survey when teachers were asked to analyze samples of student writing, 67% of teachers included in their discussion whether or not the student was using evidence in their scientific explanations and 29% commented on students' reasoning for why their evidence supported their claim. This is in contrast to their discussion of the transcripts of student talk where only 48% of the teachers discussed the role of evidence and 15% discussed the students' reasoning. Rather, the teachers tended to focus more on the teachers' questions and comments in the transcript (59%) and student interactions (26%). This suggests the importance of supporting scientific explanations and argumentation as discourse practices that are not limited to one form of communication, but rather are essential to developing an effective science classroom culture. The final poster will explore how these and other aspects of the teachers' pedagogical content knowledge changed over the course of the workshops.

Toward an emphasis on evidence and explanation in K-5 science teaching

Carla Zembal-Saul, College of Education, Pennsylvania State University, 148 Chambers Building, University Park, Pennsylvania 16802. Email: czem@psu.edu

In this work, scientific explanations can be likened to Roth's description of science content ideas (Roth et al., 2009). They are the "big ideas" accepted within the scientific community, which also serve as the intended outcomes of student learning. Engaging students in the discourse and practices of science is a means by which explanations are socially negotiated in school science.

The Framework for Teaching School Science as Argument (Zembal-Saul, 2009) leverages essential elements of inquiry (NRC, 2000), emphasizing evidence and argument in the development of scientific explanations (NRC, 2007). Three main components are fore-grounded in the framework: (1) using an argument structure to organize learning opportunities, navigate classroom discourse, and shape the science explanation; (2) reasoning publicly about the construction and evaluation of evidence-based claims; and (3) engaging authentically with the language of science. Guided by this framework, participation in investigations is not an end in itself, but rather provides the evidence for negotiating scientific explanations and making sense of science concepts. The aim is to be explicit and intentional about moving beyond activities in K-5 science teaching and toward co-constructing evidence-based explanations.

In recent years, argumentation in school science has gained support within the science education community (Driver, Newton & Osborne, 2000; Erduran & Jimenez-Aleixandre, 2008; Erduran, Simon & Osborne, 2004). This is due in part to the potential of argumentation practices to engage learners with the language of science and science learning (Mortimer & Scott, 2003), make thinking visible (Linn, 2000), and support an understanding of science concepts (Jimenez-Aleixandre, Rodriguez & Duschl, 2000). Some have suggested that arguing to learn may not be productive given how limitations in content knowledge constrain engagement with the task and quality argumentation (von Aufschnaiter et al., 2008). There is increasing evidence, however, that scaffolded argumentation can contribute to meaningful science learning (Andriessen, 2006; Clark & Sampson, 2007). Moreover, contemporary definitions of proficiency in K-8 science (NRC, 2007) identify the centrality of constructing, evaluating, and using scientific explanations, as well as participating in scientific discourse, including argumentation.

A fundamental strand of my research investigates the ways in which teacher preparation experiences informed by the argument framework mediate learning to teach science (Zembal-Saul, 2009, 2007, 2005). This poster will report on a small-scale study of five preservice elementary teachers' enrolled in their science methods course and concurrent field experience. The research questions underlying this work are: What is the nature of participants' initial science teaching? What do participants' self-analyses of teaching reveal about the ways in which they make sense of the framework? The primary sources of data were (1) video recorded science instruction of each participant, which consisted of three consecutive 45-50 minute lessons, and (2) video-based self-analyses of teaching, which consisted of 10-15 minutes of edited video with text captions justifying why particular clips were selected. The teaching events were coded using Studiocode® video analysis software, and event maps were constructed. Event maps provided a starting point for examining participants' self-analyses. Analytic categories were generated through examination of the teaching events and of the focus of preservice teachers' self-analyses. These categories helped identify the ways in which participants employed aspects of the argument framework to inform their initial science teaching, as well as how they used the framework to make sense of their practice. Results suggest that the ways in which preservice teachers think about the role of evidence in science teaching is critical for an appropriate emphasis on scientific explanations. Additionally, approaches to scientific discourse appear to be closely linked to preservice teachers' thinking about children's engagement in constructing explanations from evidence.

Disentangling conceptual and epistemic influences on scientific explanation

William A. Sandoval, Jarod Kawasaki, Graduate School of Education & Information Studies, University of California – Los Angeles, Los Angeles, California, 90095. Email: sandoval@gseis.ucla.edu, jkawasaki@ucla.edu, Tina Stanford, Sara Carriere, Bladimir Lopez-Prado, SRI International, 333 Ravenswood Ave., Menlo Park, California, 94025. Email: tina.stanford@sri.com, sara.carriere@sri.com, bladimir.lopez-prado@sri.com

Constructing a good scientific explanation would seem to require both a sound conceptual understanding of whatever is being explained and an understanding of the epistemic requirements of what makes an explanation good. The epistemic standards for a good scientific explanation have been refined historically in response to the issues that arise from not making conceptual claims and their warrants clear (Bazerman, 1988). This process of making one's claims and the evidence for them clear involves rhetorical moves aimed not just at making explanations persuasive, but comprehensible (Kitcher, 1991). For students then, learning to construct scientific explanations entails more than just learning the scientific theories and concepts that are relevant to explaining particular phenomena. It includes learning what counts as a good explanation and how to articulate one. It is not simply a cognitive skill (Kuhn & Udell, 2003; von Aufschnaiter, Erduran, Osborne, & Simon, 2008), but a complex discursive practice driven by epistemological motives that students often fail to appropriate in the science classroom (Berland & Reiser, 2009). The analysis of students' explanations of scientific phenomena, therefore, can illuminate both what students know about a particular topic – their conceptual understanding – and what they know about how to make a scientific explanation – their epistemic understanding. In practice, disentangling these influences simply by looking at students' explanations can be problematic (Kelly & Takao, 2002; Sandoval, 2003).

The study described here attempts to at least partially disentangle the influences of students' conceptual and epistemic understanding on their ability to construct good explanations for a complex question in biology. The study was conducted as part of a field test of curricular materials designed to support guided inquiry into topics of plant biology and evolution. The specific focal topics included photosynthesis, transpiration, structure-function relationships (in leaves), and evolutionary adaptation. More than 400 grade 6 and 7 students from a large, urban school district completed a three-week unit, *Why do plants look different?* The field test employed a pre-post design to measure learning of the focal topics. The capstone activity of the unit was students' investigation of remote sensing data to construct an explanation to the driving question. Analyses of the written explanations are based on a scheme that assesses three aspects of causal explanations: 1) conceptual quality; 2) degree of warrant for claims; and 3) rhetorical reference (Sandoval, 2005). That is, how well do students apply the conceptual ideas targeted in the unit to explain a complex problem; how well do they understand the epistemic criterion to have evidence for causal claims; and how well do they justify the relations between evidence and claims? These last two elements reflect students' appreciation of the epistemic demands of scientific explanation.

We pursue two questions in our analysis, which is currently underway. The first is whether or not students' prior knowledge, as measured by the pre-test, predicts their performance on the explanation task. We expect that prior knowledge should only affect scores of conceptual quality, if anything. If this expectation holds true, it would suggest students learning something important during the unit about the epistemic demands of explanation. If, on the other hand, all three aspects of explanation performance are predicted by pre-test score, it would support the claim that conceptual knowledge is what separates good explanations from bad. A second question we pursue is whether or not performance on the explanation task, particularly on the epistemic aspects of the task, predicts learning gains from the unit. If so, it would suggest that learning the epistemic demands of scientific explanation help to consolidate, at the very least, conceptual understanding when learning science. Whatever the specific outcomes of our analyses, they will clarify the influences of conceptual and epistemic understanding on students' efforts to construct, and learn from, scientific explanation.

Towards a Taxonomy of Explanations in Science Education

Barbara White, Jennifer L. Chiu, Lauren Barth-Cohen, Beat Schwendimann, Eric Berson, Jennifer King Chen,
Hillary Swanson, University of California, Berkeley, Berkeley CA, 94720. Email: bywhite@berkeley.edu,
jenchiu@berkeley.edu, lbarth@berkeley.edu, bschwendimann@berkeley.edu, eberson@berkeley.edu,
jykchen@berkeley.edu, hswanson@berkeley.edu

One major goal of science education is for students to develop sophisticated explanations of the natural world (NRC, 2000). Scientists create and revise conceptual scientific models that they employ to develop and refine explanations. Scientists also have distinct forms and criteria for accepted explanations. Likewise, inquiry-based teaching enables students to ask questions, develop conceptual models and explanations, and critique and refine their explanations. However, students build upon existing, everyday ideas to make explanations that are different than those of scientists and judge explanations differently than the way that scientists judge them (Brewer, Chinn & Samarapungavan, 1998). Most existing approaches evaluate students’ explanations along scientific criteria and overlook learners’ existing ideas and skills in generating explanations. Instruction that encourages students to use, distinguish and refine these existing ideas can promote sophisticated and robust explanations (Linn & Eylon, 2006).

We aim to characterize learners' existing and developing explanatory capabilities by creating a taxonomy of explanations that builds from literature in psychology, cognitive science, philosophy of science, and science education. Existing definitions and operationalizations of scientific explanations tend to be specific to particular domains with widely varying grain sizes. We see students' explanations containing a variety of ideas and forms that cut across these existing taxonomies. For example, students may have naïve ideas about a scientific phenomenon yet use sophisticated deductive reasoning within their explanation. Students can provide insight into their understanding of causal mechanisms using narrative forms in explanations. A broad taxonomy of explanations that builds upon the diversity of expert and novice explanations can capture these varied types of ideas and reasoning. By doing so, a general taxonomy can identify the fruitful aspects of explaining that novices gain from everyday experience, as well as identify aspects of expert explanations that novices should develop. Ultimately, this taxonomy can guide curriculum and assessment development, and help students and teachers develop a meta-level understanding of what constitutes a good explanation.

This poster presents our taxonomy as developed from our review of the literature and refined through coding of student and expert explanations in various domains. Our taxonomy outlines general categories of purpose, form, content, characteristics, reasoning, and meta-talk. *Purpose* identifies causality and mechanism within the explanation. The *form* category captures the overall structure of the causal explanation, such as a causal chain or cyclical causality. *Content* distinguishes specific domain ideas used, such as laws or facts. *Characteristics* include attributes of explanations that have been identified as important in the literature, such as generalizability or varying perspectives. *Reasoning* captures the various forms of reasoning embedded within explanations, such as deductive or inductive reasoning. *Meta-talk* captures the explainer's higher-level knowledge about what makes a good explanation and what are good strategies for explaining, as well as regulatory awareness, such as monitoring of the effectiveness of an explanation. Our poster will present these categories in detail with data from expert and student explanations.

References

Amsterlaw, J., & Wellman, H. (2006). Theories of mind in transition: A microgenetic study of the development of false belief understanding. *Journal of Cognition and Development,* 7, 139–172.

Andriessen, J. (2006). Arguing to learn. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences.* Cambridge, NY: Cambridge University Press.

Bazerman, C. (1988). *Shaping written knowledge: The genre and activity of the experimental article in science.* Madison, WI: University of Wisconsin Press.

Berland, L. K, & Reiser, B. J. (2009). Making sense of argumentation and explanation. *Science Education, 93*, 26-55

Brewer, W. F., Chinn, C. A., & Samarapungavan, A. (1998). Explanation in scientists and children. *Minds and Machines, 8*, 119 – 136

Chi, M.T.H. (2000). Self-explaining: The dual processes of generating inferences and repairing mental models. In R. Glaser (Ed.), Advances in Instructional Psychology (pp. 161–237). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Chi, M. T. H., de Leeuw, N., Chiu, M.H., & LaVancher, C. (1994). Eliciting self-explanation improves understanding. *Cognitive Science*, 18, 439–477.

Clark, D. & Sampson, V. (2007). Personally-seeded discussions to scaffold online argumentation. *International Journal of Science Education, 29(3),* 253-278.

Crowley K. & Siegler, R. S. (1999) Explanation and generalization in young children's strategy learning. *Child Development,* 70, 2 pp. 304-316

Davis, E. A. & Krajcik, J. S. (2005). Designing educative curriculum materials to promote teacher learning. *Educational researcher, 34*(3), 3-14.

Driver, R. Newton, P. & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education.* 84, 287-312.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (Eds.). (2007). *Taking science to school: Learning and teaching science in grades k-8.* Washington D.C.: National Academy Press.

Erduran, S., & Jiménez-Aleixandre, M. P. (Eds.). (2008). *Argumentation in science education: perspectives from classroom-based research*. Dordrecht: Springer.

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulimin's argument pattern for studying science discourse. Science Education, 88(6), 915 – 933.

Jiménez-Aleixandre, M., Rodriguez, A., & Duschl, R. (2000). "Doing the lesson" or "doing science": Argument in high school genetics. Science Education, 84(6), 757–792.

Jiménez-Aleixandre, M. P. & Erduran, S. (2008). Argumentation in science education: An Overview. In S. Erduran & M. P. Jimenez-Aleixandre (Eds.). *Argumentation in science education: Perspectives from classroom-based research*. (pp. 3-28), Dordrecht: Springer.

Kelly, G. J., & Takao, A. (2002). Epistemic levels in argument: an analysis of university oceanography students' use of evidence in writing. *Science Education, 86*, 314-342.

Kitcher, P. (1991). Persuasion. In M. Pera & W. R. Shea (Eds.), *Persuading science: the art of scientific rhetoric* (pp. 3-27). Canton, MA: Science History Publications.

Kuhn, D., & Udell, W. (2003). The development of argument sklls. *Child Development 74*(5), 1245-1260.

Linn, M. (2000). Designing the knowledge integration environment. International Journal of Science Education, 22(8), 781 – 796.

Linn, M. C., & Eylon, B. –S. (2006). Science education. In P. A. Alexander & P. H. Winne (Eds.) *Handbook of Educational Psychology*, *2nd edition.* Mahwah, NJ: Erlbaum.

Lombrozo, T. (2006). The structure and function of explanations. *Trends of Cognitive Sciences*, *10* (10), 464-470.

McNeill, K. L., Lizotte, D. J, Krajcik, J., & Marx, R. W. (2006). Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *The Journal of the Learning Sciences, 15*(2), 153-191.

Miles, M., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook (2nd edition).* Thousand Oaks, CA: Sage.

Mortimer, E., & Scott, P. (2003). Meaning making in secondary science classrooms. McGraw-Hill International.

Murphy, G. L., & Medin, D. L. (1985). The role of theories in conceptual coherence. *Psychological Review, 92,* 289-316.

Nagel, E. (1961). *The structure of science: Problems in the logic of science education.* New York, NY: Harcourt, Brace, & World, Inc.

National Research Council (2000). *Inquiry and the national science education standards.* Washington, D.C.: National Academy Press.

National Research Council (2007). *Taking science to school: Learning and teaching science in grades K-8.* Washington, D.C.: National Academy Press.

Newton, P., Driver, R., & Osborne, J. (1999). The place of argumentation in the pedagogy of school science. *International Journal of Science Education*, 21(5), 553-576.

Roth, K., Chen, C., Lemmens, M., Garnier, H., Wickler, N., Atkins, L., Calabrese Barton, A., Roseman, J. Shouse, A. & Zembal-Saul, C. (2009). Coherence and science content storylines in science teaching: Evidence of neglect? Evidence of effect?

Sandoval, W. A. (2003). Conceptual and epistemic aspects of students' scientific explanations. *Journal of the Learning Sciences, 12*(1), 5-51.

Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education 89*(4), 634-656.

Siegler, R. S. (2002). Microgenetic studies of self-explanations. In N. Granott & J. Parziale (Eds.), *Microdevelopment: Transition processes in development and learning* (pp. 31-58). New York: Cambridge University.

Simon, S., Erduran, S. & Osborne, J. (2006). Learning to teach argumentation: Research and development in the science classroom. *International Journal of Science Education, 28*(2-3), 235-260.

von Aufschnaiter, C., Erduran, S., Osborne, J. & Simon, S. (2008). Arguing to learn and learning to argue: Case studies of how students' argumentation relates to their scientific knowledge. *Journal of Research in Science Teaching*, 45(1), 101-131.

Zembal-Saul, C. (2009). Learning to teach elementary school science as argument. *Science Education,* 93(4), 687-719.

Zohar, A. (2008). Science teacher education and professional development in argumentation. In S. Erduran & M. P. Jimenez-Aleixandre (Eds.). *Argumentation in science education: Perspectives from classroom-based research.* (pp. 245-268), Dordrecht: Springer.