Without Conceptual Information Children Miss the Boat: Examining the Role of Explanations and Anomalous Evidence in Scientific Belief Revision

Nicole E. Larsen† **(nicole.larsen@mail.utoronto.ca), Vaunam P. Venkadasalam**†
(vaunam.venkadasalam@mail.utoronto.ca) & Patricia A. Ganea (patricia.ganea@utoronto.ca)
Department of Applied Psychology & Human Development,
University of Toronto, 252 Bloor St West, Toronto, Ontario, M5S 1V6
†*Authors contributed equally.*

Abstract

In this study we investigated the role of conceptually rich explanations and anomalous evidence in children's scientific belief revision. We also explored whether the order in which children experience these two learning opportunities influences their belief revision ability. Five-year-old children were assigned to one of two conditions, where they either first received conceptual explanations about buoyancy and then observed anomalous data in a guided activity (*Explanation-First*), or the reverse (*Anomalies-First*). Results showed that (1) conceptually rich explanations lead to more accurate predictions about which objects sink and which float than anomalous data presentation, and (2) when explanations and anomalous data were combined, children's correct predictions increased significantly from pre-test to post-test when they received the conceptual information before the anomalous evidence (*Explanation-First*), but not in the opposite order condition (*Anomalies-First*). These results suggest that children are more likely to maintain their misconceptions when exposed to anomalies without prior instruction involving conceptually rich explanations.

Keywords: cognitive development; belief revision; scientific reasoning

Supporting Scientific Belief Revision

Scientific beliefs have their foundations in early development. Much of children's early science learning is informal, and the intuitive theories they build through daily observation and cultural learning are frequently at odds with accurate scientific theories (Kuhn, 1989; Vosniadou & Brewer, 1992). Children's naïve misconceptions are often resistant to change (Vosniadou, 2002) and some persist into adulthood (Coley & Tanner, 2012; Pine, Messer, & St. John, 2001; Shtulman & Valcarcel, 2012). Conceptual change is the process of restructuring naive theories to include counter-intuitive concepts, which for some scientific domains can be a lengthy and arduous process (Vosniadou, 2013).

The process of early scientific reasoning has been compared to formal scientific theory change, in which children get to formulate, test, and revise hypotheses based on evidence and observations (Gopnik, 2012; Gopnik & Wellman, 2012). As part of this process, experiencing anomalous evidence that contradicts existing naïve theories is an important driver of belief revision. For example, some existing research suggests that, depending on which type of anomalous data they observe, preschool children either explain away or change their naïve theories about how objects balance (Bonawitz, Van Schijndel, Friel, & Schulz, 2012).

However, anomalous data may not always be sufficient for facilitating belief revision. Research about causal systems has indicated that when children are shown novel causal systems, they can theorize about the causal relation in these systems, and are subsequently resistant to changing these theories, even when immediately presented with new anomalous data (Schauble, 1990; Schulz, Goodman, Tenenbaum, & Jenkins, 2008). This is compounded by the fact that although providing children with anomalous data presents an opportunity for belief revision, children often make errors during the observation, interpretation, generalization, or retention stages of science activities when they encounter anomalous evidence (Chinn & Malhotra, 2002).

In the case of existing misconceptions, children's tendency to hold onto naïve theories may be even more pronounced as these theories are more entrenched. Children's difficulty in making inferences from evidence that is in conflict with their naïve theories may result from the absence of a viable alternative theory (Chinn & Brewer, 1993). If children are provided with alternative explanations, they may be better equipped to interpret the anomalous data they encounter and as a result be more likely to engage in belief revision. Thus, combining anomalous evidence with correct conceptual explanations may be particularly effective for belief revision and science learning more generally (Koslowski, 1996).

Current Study

The goal of the current study was twofold. First, we examined the role of conceptually rich explanations and anomalous evidence in children's ability to revise an existing naïve scientific belief. Second, we explored whether the order in which children experience these two learning opportunities influences their belief revision ability. Five-year-old children were provided with conceptually rich information about buoyancy (during a brief picture book reading session) either before or after they had the opportunity to observe anomalous examples (i.e., heavy objects floating) in a guided play activity. We selected to deliver the conceptually rich explanations in a picture book format not only because picture-book reading is an enjoyable activity for many young children, but also because research has shown that young children can learn scientific information from picture books, even in cases where they hold misconceptions (Kelemen, Emmons, Seston Schillaci, & Ganea, 2014; Venkadasalam & Ganea, 2018). We presented anomalous evidence through a guided activity, which allowed for active engagement with real, physical objects (Nayfeld, Brenneman, & Gelman, 2011; Peterson & French, 2008). Here, we were interested in how children interpret and generalize from real-life anomalous evidence. In guided activities, adults plan an activity with a learning goal, and scaffold this learning, which allows children to maintain an active role in the process (Weisberg, Hirsh-Pasek, & Golinkoff, 2013). Thus, guided activities provided children with hands on opportunities to interact with anomalous evidence in an engaging way, but also ensured that they were able to produce such evidence with guidance.

We examined belief revision in children's acquisition of a physical science concept (buoyancy), a concept with common misconceptions. Buoyancy is the upward force on objects in a liquid. An object floats if the buoyant force is equal to the force of gravity, and an object sinks when the gravitational force is stronger. Sinking and floating are concepts taught throughout science education (Kallery, 2015; Selley, 1993) and ones for which children often hold misconceptions (Hardy, Jonen, Möller, & Stern, 2006; Yue, Tomita, & Shavelson, 2008). One difficulty young children have is that they often conflate density with weight (Wilkening & Cacchione, 2011), which is problematic when children have to compare the relative densities of the objects and water, often leaving them with the misconception that heavy objects sink and light objects float (Lehrer, Schauble, Strom, & Pligge, 2011; Smith, Carey, & Wiser, 1985). When 5-year-old children notice anomalies to their intuitive theories ("heavy objects sink and light objects float") they sometimes hypothesize about the material of the objects (e.g., wooden objects float). A focus on material is a promising step in children's ability to think about density because some materials are less dense than others and therefore sink at different rates. However, to fully understand what makes objects sink or float, children also have to consider how the mass is distributed and therefore take into account the shape of the object as well. Here we explore the effect of pairing anomalies with conceptually rich explanations to promote children's ability to dissociate the objects' behavior in water from their weight and recognize the role of air-filled cavities and surface tension in explaining why objects sink or float.

The study was designed using a pre-, mid-, and post-test to measure children's belief revision. In each test phase, we examined differences in children's predictions of whether objects would sink or float as a function of the order of instructional methods used (conceptual information or anomalous data). Children's predictions were chosen as an implicit measure of learning. The pre-test allowed us to control for children's previous knowledge. The mid-test allowed us to determine the role of each learning opportunity (explanations or anomalous evidence) on children's belief revision in isolation. Finally, the post-test was used to determine whether the order in which children received the two learning opportunities mattered when they were combined.

We expected that, when compared to pre-test scores, children's predictions at mid-test about which objects float or sink would be significantly higher in the *Explanation-First* condition but not the *Anomalies-First* condition. There is previous research showing that children are able to learn scientific information from conceptually rich explanations (Kelemen et al., 2014; Venkadasalam & Ganea, 2018) and we expected to find the same type of evidence here. However, given the existing research with adults on the use of anomalous evidence indicating that individuals often make errors in the interpretation and generalization of this evidence (Chinn & Malhotra, 2002), we expected that the exposure to anomalies alone will not lead to a change in children's misconceptions.

With respect to the order in which children receive the conceptually rich information and the anomalous evidence, we considered the possibility that children who received the anomalous data first may make comparable gains at post-test after receiving the conceptual information. However, although possible this is not very likely, because without an alternative theory to explain the anomalies, children could appeal to extraneous variables to fit the anomalous evidence into their naïve theory, therefore strengthening it. As a result, the hypothesized difference at mid-test would remain significant at post-test, even after exposure to an alternative theory. The alternative order of presentation (explanations followed by anomalies) might be more effective, because children could rely on the conceptual information provided to interpret the anomalous evidence.

Methods

Participants

Ninety-six 5-year-old children (M = 5.49; range: 5.03- 5.99, 48 males) participated in this study. Equal numbers of children were randomly assigned to one of two conditions: *Explanation-First* (n = 48, M_{age} = 5.50, 24 males, 24 females), and *Anomalies-First* (n = 48, M_{age} = 5.49, 24 males, 24 females). Within these conditions, children were read one book and completed one activity. We developed two books and two guided activities to teach children about buoyancy. This was done to ensure that differences in learning did not arise from the type of book the child read or the activity the child completed. All 16 combinations of the books and activities were included and were counterbalanced, such that 6 children received each possible combination. No differences between the two types of books and activities were expected.

Procedure

There were five phases in this study: a pre-test, a learning phase 1 (depending on the condition, *Explanation-First* or *Anomalies-First*), mid-test phase, learning phase 2 (Explanation/Anomalies, depending on the condition), and the post-test. The session was video-recorded and lasted 40 minutes to 1 hour.

Test Phase. To measure children's belief revision a pre-, mid- and post-test were administered. The procedure for the pre-, mid-, and post-test was identical. The materials for each of the 3 test phases included 4 pairs of objects, for a total of 12 objects pairs. Within each set of 4 pairs, two pairs of objects were the same weight, and two were different weights. Two of the pairs of objects were made of the same material and two were made of different materials. Materials included: metal, plastic, rubber, and glass. For each test phase, children received a different object set, but the order in which children received these sets was counterbalanced across the pre-, mid- and post-tests.

Children were given objects in pairs to inspect. The experimenter told children what each object was made of so there was no ambiguity. Children were then provided with a scale and prompted to weigh the object pairs so they could definitively identify which object was heavier and which was lighter. To avoid differences in response patterns within the sample, within each object set the pairs of objects were presented in the same order to each participant: different weight/different material, same weight/same material, same weight/different material, and different weight/same material.

After children were given time to inspect and feel the objects, weigh them, and were told what they were made of, children were asked the test question: "If I took these two objects and put them into the water, which one would float on the top and which one would sink to the bottom?". Their predictions were recorded. Children received neutral feedback ("Thank you") after answering each question.

Learning Phase. In this phase, we used picture books to deliver the conceptually rich explanations and guided activities to present children with the anomalous evidence. We developed two books and two guided activities to ensure that differences in learning did not arise from the type of book or activity used. For the picture books, we created an informational, non-fiction book, and a narrative, fiction book which contained the same conceptual information about buoyancy. Given previous work reporting no differences in children's learning based on book genre, we did not expect to find differences between these two book types (Venkadasalam & Ganea, 2018).

In the first guided activity, Activity One, children made predictions about whether 12 different objects would sink or float. The objects in this activity varied in weight and material. Children then tested these objects in water to see if their predictions were correct. The second activity, Activity Two, involved children manipulating a piece of clay into shapes that either floated or sank. Children then tested these shapes in water, demonstrating that an object with a constant weight can both sink and float. No differences were expected between activities as children were guided through each activity to ensure the production and observation of anomalous evidence and both activities were designed to demonstrate the same type of anomalies.

Children in the *Explanation-First* condition were read the book prior to the activity, whereas children in the *Anomalies-First* condition were read the book following the activity. During the book reading, the experimenter read either the non-fiction or the fiction book to each child aloud. In the activity, the experimenter guided children through different instances where they could compare objects sinking and floating, either with the 12 objects in Activity One, or the pieces of clay in Activity Two. The books and activities were structured to be analogous in terms of their content. The goal of both learning phases was explicitly identified as teaching children about why objects sink or float. However, no mention of the book was made during the activity, and likewise no mention of the activity was made during the book.

Coding

Children's predictions for which object would sink and which one would float in each pair were scored. Children who correctly identified which object in the pair would sink and which would float received a score of 1. A score of 0 was assigned if children incorrectly identified the sinker and the floater in the object pair or if they said both objects would sink or both objects would float. Two research assistants coded 100% of the children's responses from the video recordings. The coders were blind to the hypotheses of the study, the condition and test phase. There was high interrater reliability determined by Cohen's $\kappa = .91$, $p < .001$, a 95.66% agreement rate. The coders resolved disagreements through discussion.

Results

In preliminary analyses, we ensured there were no differences between the scores at mid- and post-test as a result of the two types of books and activities used. A Mann Whitney U-test found that scores for mid- and post-test were similar for both books (*ps* > .84), and both activities (*ps* > .12). As there were no significant differences between the type of books and activities used in the intervention, these factors were collapsed in the following main analyses. We also examined differences between children's knowledge across the two conditions at pre-test. A Mann Whitney U-test found that the pre-test scores were similar across conditions at baseline, $U = 1017$, $z = -1.02$, $p = .31$ with a mean rank pre-test score of 45.69 for the *Explanation-First* condition and 51.31 for the *Anomalies-First* condition. Additionally, Wilcoxon Signed-ranks tests revealed that the pre-test scores were significantly lower than chance responding, indicating that children held misconceptions at pre-test (*Explanation-First*: $Z = -3.35$, $p =$

.001; *Anomalies-First:* Z = -2.32, p = .021). Table 1 displays the proportion of correct responses across the three test phases for both conditions.

A generalized estimating equation (GEE) analysis with multinomial distributions and cumulative logit link functions was conducted to investigate whether children correctly predicted which object would sink and which would float. This type of analysis was selected to accommodate the ordinal dependent variable and the presence of a within-subject factor (pre-, mid- and post-test scores) in the data.

Table 1: Percent Correct Responses Across Test Phases by Condition.

Score	Test Phase					
	Pre-Test		Mid-Test		Post-Test	
	Anom -First	Expl -First	Anom -First	Expl-First	Anom-First	Expl-First
0/4	27%	40%	27%	19%	25%	8%
1/4	19%	19%	21%	0%	15%	15%
2/4	33%	19%	27%	27%	25%	8%
3/4	13%	17%	15%	27%	21%	38%
4/4	8%	6%	10%	27%	15%	31%

Notes. Anom-First stands for the *Anomalies-First* condition. Expl-First stands for the *Explanation-First* condition. The percentages are calculated out of 48 total responses for each condition per test phase.

There was no effect of condition, (p = .31), nor a difference between pre- and mid-test (p = .80), nor pre- and post-test (p = .10). However, there was a significant interaction between condition and test phase. From pre- to mid-test children in the *Explanation-First* condition were more likely to answer more test questions correctly, Wald $\chi 2(1) = 19.87$, $p < .001$, b = 1.51, SE = .34, compared to the *Anomalies-First* condition. Children in the *Explanation-First* condition (Exp(B) = 4.51, 95% CI = [2.33, 8.75]) were approximately four and a half times more likely to answer the test questions correctly at mid-test in comparison to the *Anomalies-First* condition.

Additionally, from pre- to post-test children in the *Explanation-First* condition were more likely to answer more test questions correctly, Wald $\chi 2(1) = 14.66$, $p < .001$, b = 1.53, SE = .40, compared to the *Anomalies-First* condition. Children in the *Explanation-First* condition (Exp(B) = 4.62, 95% CI = [2.11, 10.09]) were approximately four and a half times more likely to answer the test questions correctly at post-test in comparison to the *Anomalies-First* condition.

Post-hoc Wilcoxon Signed Rank Tests were conducted using a Bonferroni correction to account for multiple comparison (alpha = .008). There was a significant increase in children's score in the *Explanation-First* condition between pre- and mid-test (z = 4.45, p < .001) and pre- and post-test (z = 4.86, p < .001), but not between mid- and post-test (z = 1.63, p = .10). In the *Anomalies-First* condition there was no significant increase in scores for any of the test phases (ps > .13); see Figure 1.

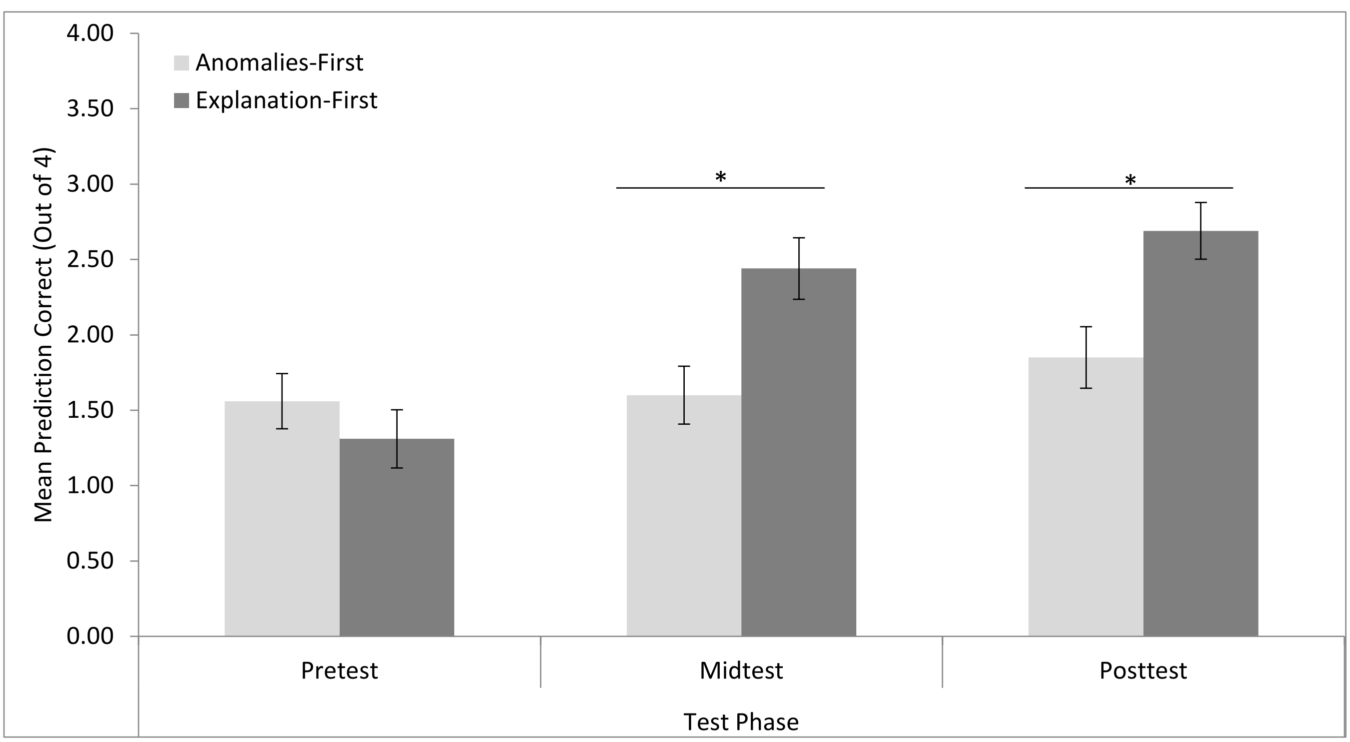

Figure 1: Mean Predictions Correct across Test-Phase by Condition

Discussion

This study investigated the role of conceptually rich explanations and anomalous evidence in children's revision of physical science misconceptions. We first found that children can revise their belief about what makes objects float or sink when provided only with a conceptual explanation but not when only witnessing anomalies. Compared to pre-test scores, children in the *Explanation-First* condition made significantly better predictions at mid-test after they received the conceptual information only. However, the children in the *Anomalies-First* condition did not make significantly better predictions after observing anomalies. This indicates that children maintain their misconceptions when they have exposure to anomalies.

We also found that the order of instructional methods affects children's belief revision in the context of a physical science concept. Children performed better at post-test when presented with rich conceptual explanations *prior to* observing anomalous evidence. The *Explanation-First* condition facilitated greater revision of beliefs than the *Anomalies-First* condition. Of note, even in the *Explanation-First* condition, when children observed anomalous evidence after they received the explanations, the anomalies did not lead to any significant changes. In contrast, results from the *Anomalies-First* condition showed that observing the anomalies first subsequently interfered with children's ability to incorporate and apply the conceptual information they received from the picture book.

Together these findings provide evidence that using anomalous data to promote belief revision can be challenging, as children are biased to rely on their own theories, and resistant to setting aside this prior knowledge when confronted with counter-evidence (Chinn & Brewer, 1993; Kuhn et al., 1988). Despite observing counterexamples, children may ignore them, or even find a way to fit the anomalies within their existing theoretical framework, thereby strengthening their naïve misconceptions. However, when children have access to a viable, alternative explanatory framework, they can then activate this alternative theory to interpret the anomalous evidence. Thus, the present findings indicate that supplementing prior beliefs with an alternative conceptual explanation before anomalous evidence is observed may be particularly effective for promoting knowledge revision.

Further work is needed to determine if the addition of anomalous evidence affects retention after a delay. That is, while we found no positive effects of the anomalous evidence above and beyond what the explanations provided, observing anomalous evidence after receiving the correct explanation, may lead to greater retention of the new theory than receiving only the explanation alone.

Another consideration for future work is that explicit connections were not made between the book and the activity. While these learning phases were built to be highly analogous, and the same content goal was verbally specified for both, no explicit connection was made between them. It is possible that with an explicit connection between the two, children may achieve higher performance across conditions.

Additionally, in the current study the explanations were presented through a picture book. It is an open question whether results would be similar if both the explanations and anomalies are presented in a similar manner. Currently, we are exploring whether pairing live anomalous evidence with verbal explanations will have positive effects on learning. Further work should also explore the applicability of these findings to different scientific concepts. Sinking and floating are complex physical concepts, particularly for young children to grasp. It is possible that presenting children with anomalies only or first may be equally effective for belief revision for simpler concepts.

The current results can inform our theories about the process of conceptual change and optimal science instruction. This study demonstrates the importance of critically examining not just *what* we teach children, but *how* we teach them, and in particular the order in which instruction is delivered. Presenting children with content information before they observe anomalous data prevents children from fitting anomalies into their naïve schema, giving them an alternative viewpoint from which to interpret this evidence. Therefore, this order of presentation better facilitates the revision of children's misconceptions. Providing children with comprehensive explanations of phenomena they observe is a promising educational technique to improve their scientific reasoning and literacy.

Acknowledgments

We are grateful to the children who participated in this research and we thank the families who made this possible. We would like to thank Angela Nyhout, Myrto Grigoroglou and Begum Ozdemir for feedback on a previous draft of this paper. This research was supported by a SSHRC Insight grant to Patricia Ganea.

References

Bonawitz, E. B., Van Schijndel, T. J. P., Friel, D., & Schulz, L. (2012). Children balance theories and evidence in exploration, explanation, and learning. *Cognitive Psychology*, *64*, 215–234. https://doi.org/10.1016/j.cogpsych.2011.12.002

Chinn, C. A., & Brewer, W. F. (1993). The Role of Anomalous Data in Knowledge Acquisition: A Theoretical Framework and Implications for Science Instruction. *Review of Educational Research*, *63*(1), 1–49. https://doi.org/10.3102/00346543063001001

Chinn, C. A., & Malhotra, B. A. (2002). Children's responses to anomalous scientific data: How is conceptual change impeded? *Journal of Educational Psychology*, *94*(2), 327–343. https://doi.org/10.1037/0022-0663.94.2.327

Coley, J. D., & Tanner, K. D. (2012). Feature Approaches to Biology Teaching and Learning Common Origins of Diverse Misconceptions: Cognitive Principles and the Development of Biology Thinking. *Life Sciences Education*, *11*, 209–215.

https://doi.org/10.1187/cbe.12-06-0074
Gopnik, A. (2012). Scientific Thinking in Young Children: Theoretical Advances, Empirical Research, and Policy Implications. *Science*, *337*(6102), 1623–1627.
Gopnik, A., & Wellman, H. M. (2012). Reconstructing constructivism: Causal models, Bayesian learning mechanisms, and the theory theory. *Psychological Bulletin*, *138*(6), 1085–1108. https://doi.org/10.1037/a0028044
Hardy, I., Jonen, A., Möller, K., & Stern, E. (2006). Effects of instructional support within constructivist learning environments for elementary school students' understanding of "floating and sinking." *Journal of Educational Psychology*. https://doi.org/10.1037/0022-0663.98.2.307
Kallery, M. (2015). Science in early years education: introducing floating and sinking as a property of matter. *International Journal of Early Years Education*, *23*(1), 31–53. https://doi.org/10.1080/09669760.2014.999646
Kelemen, D., Emmons, N. A., Seston Schillaci, R., & Ganea, P. A. (2014). Young Children Can Be Taught Basic Natural Selection Using a Picture-Storybook Intervention. *Psychological Science*, *25*(4), 893–902. https://doi.org/10.1177/0956797613516009
Koslowski, B. (1996). *Learning, development, and conceptual change. Theory and evidence: The development of scientific reasoning.* Cambridge, MA, US: The MIT Press.
Kuhn, D. (1989). Children and Adults as Intuitive Scientists. *Psychological Review*, *96*(4), 674–689. https://doi.org/10.1037/0033-295X.96.4.674
Kuhn, D., Amsel, E., O'Loughlin, M., Schauble, L., Leadbeater, B., & Yotive, W. (1988). *The development of scientific thinking skills. The development of scientific thinking skills.* San Diego, CA, US: Academic Press.
Lehrer, R., Schauble, L., Strom, D., & Pligge, M. (2011). Similarity of form and substance: Modeling material kind. In S. M. Carver & D. Klahr (Eds.), *Cognition and instruction : twenty-five years of progress* (pp. 39–74). Psychology Press.
Nayfeld, I., Brenneman, K., & Gelman, R. (2011). Science in the Classroom: Finding a Balance Between Autonomous Exploration and Teacher-Led Instruction in Preschool Settings. *Early Education and Development*. https://doi.org/10.1080/10409289.2010.507496
Peterson, S. M., & French, L. (2008). Supporting young children's explanations through inquiry science in preschool. *Early Childhood Research Quarterly*. https://doi.org/10.1016/j.ecresq.2008.01.003
Pine, K., Messer, D., & St. John, K. (2001). Children's Misconceptions in Primary Science: A Survey of teachers' views. *Research in Science & Technological Education*, *19*(1), 79–96. https://doi.org/10.1080/02635140120046240
Schauble, L. (1990). Belief revision in children: The role of prior knowledge and strategies for generating evidence. *Journal of Experimental Child Psychology*, *49*(1), 31–57. https://doi.org/10.1016/0022-0965(90)90048-D
Schulz, L. E., Goodman, N. D., Tenenbaum, J. B., & Jenkins, A. C. (2008). Going beyond the evidence: Abstract laws and preschoolers' responses to anomalous data. *Cognition*, *109*(2), 211–223. https://doi.org/10.1016/j.cognition.2008.07.017
Selley, N. (1993). Why do things float? A study of the place for alternative models in school science. *School Science*, *74*(269), 55–61.
Shtulman, A., & Valcarcel, J. (2012). Scientific knowledge suppresses but does not supplant earlier intuitions. *Cognition*, *124*(2), 209–215. https://doi.org/10.1016/j.cognition.2012.04.005
Smith, C., Carey, S., & Wiser, M. (1985). On differentiation: A case study of the development of the concepts of size, weight, and density. *Cognition*, *21*(3), 177–237. https://doi.org/10.1016/0010-0277(85)90025-3
Venkadasalam, V. P., & Ganea, P. A. (2018). Do objects of different weight fall at the same time? Updating naive beliefs about free-falling objects from fictional and informational books in young children. *Journal of Cognition and Development*, *19*(2), 165–181. https://doi.org/10.1080/15248372.2018.1436058
Vosniadou, S. (2002). On the Nature of Naïve Physics. In M. Limon & L. Mason (Eds.), *Reconsidering Conceptual Change: Issues in Theory and Practice.* (pp. 61–76). Dordrecht: Springer.
Vosniadou, S. (2013). Conceptual Change in Learning and Instruction. In S. Vosniadou (Ed.), *International Handbook of Research on Conceptual Change* (p. 768). New York, NY: Routledge.
Vosniadou, S., & Brewer, W. F. (1992). Mental models of the Earth: A study of conceptual change in childhood accepted information that the earth is a sphere. *Cognitive Psychology*, *585*(24), 535–585. https://doi.org/10.1016/0010-0285(92)90018-W
Weisberg, D. S., Hirsh-Pasek, K., & Golinkoff, R. M. (2013). Guided Play: Where Curricular Goals Meet a Playful Pedagogy. *Mind, Brain, and Education*, *7*(2), 104–112. https://doi.org/10.1111/mbe.12015
Wilkening, F., & Cacchione, T. (2011). Children's intuitive physics. In U. C. Goswami (Ed.), *The Wiley-Blackwell handbook of childhood cognitive development* (pp. 473–496). Maiden: Wiley-Blackwell.
Yue, Y., Tomita, M. K., & Shavelson, R. J. (2008). Diagnosing and Dealing with Student Misconceptions: Floating and Sinking. *Science Scope*, *34*(1), 34–39.
Zimmerman, C. (2007). The development of scientific thinking skills in elementary and middle school. *Developmental Review*, *27*(2), 172–223. https://doi.org/10.1016/j.dr.2006.12.001