Chapter 12
A Responsive Methodological Construct for Supporting Learners' Developing Modeling Competence in Modeling-Based Learning Environments

Todd Campbell, Thomas J. McKenna, Jihyun An, and Laura Rodriguez

12.1 Introduction

Science studies research has revealed how models serve as context dependent tools for organizing the day-to-day sensemaking work of scientists (Passmore, Gouvea, & Giere, 2014). When this is considered in recent calls for science learning environments to position students as legitimate participants in the social, epistemic, and material dimensions of science (Ford & Forman, 2006; Lehrer & Schauble, 2006), modeling-based learning (MBL) classroom environments (Louca & Zacharia, 2012) emerge as important for more authentically representing scientific activity and supporting students' developing modeling competence as they focus on explaining events that happen in the world. Here, the notion of modeling competence is framed in alignment with the functional-pragmatic concept of competence, especially since the main focus is on supporting students' abilities to cope with challenges (e.g., explaining phenomena) and using models as epistemic tools across a range of contexts (Klieme, Hartig, & Rauch, 2008). Therefore, the importance of MBL environments lies in how models are used by students as epistemic tools for organizing their day-to-day work across instructional units. In this, students are positioned as epistemic agents (Scardamalia, 2002; Stroupe, 2014) to work at knowing with modeling as a central knowledge development practice (Sandoval, 2015) that is stabilized through the interplay of their (i.e., students') ideas, the material

---

T. Campbell (✉) · J. An
University of Connecticut, Storrs, CT, USA
e-mail: todd.campbell@uconn.edu

T. J. McKenna
Boston University, Boston, MA, USA·

L. Rodriguez
Eastern Connecticut State University, Willimantic, CT, USA

A. Upmeier zu Belzen et al. (eds.), *Towards a Competence-Based View on Models and Modeling in Science Education*, Models and Modeling in Science Education 12, https://doi.org/10.1007/978-3-030-30255-9_12

world, evidences, and other practices in representations of scientific activity (Ford, 2005; Manz, 2015; Pickering, 1995; Rouse, 2007).

However, because the work of supporting students' engagement in modeling is complex, increased attention is needed for understanding the role of teachers in these learning environments (Griesemer, Lo, Guy, Harris, & Passmore, 2016; Kahn, 2011; Schwarz et al., 2016), especially when teachers work to position students as epistemic agents and their ideas as resources for sensemaking within these environments. Given this, a methodological construct that teachers can use in MBL environments to support sensemaking with students' ideas is the focus of this chapter. More specifically, redirection is the primary methodological construct that is explored in this chapter in the context of a high school physics classroom. It is foregrounded in the study of a MBL environment because of how it was previously found to be useful in support of sensemaking with students' ideas in classroom communities (Lineback, 2015), especially since sensemaking with students' ideas (e.g., partial understanding of scientific ideas, nonstandard ideas, and everyday experiences) is at the very heart of the epistemic practice of modeling (Gouvea & Passmore, 2017). Further, responsive teaching is prioritized as a central priority of redirection that supports teachers as an approach for taking up their students' ideas 'in the moment' and helping foreground those ideas so that the anchoring practice of modeling in the MBL environment supports the refinement of students' ideas. More specifically, Lineback described *redirection* "as instances when a teacher invites students to shift or redirect their attention to a new locus" (p. 419). Through redirection, teachers can support students by foregrounding (un)productive ideas so that they can use localized ways of knowing, especially modeling as a knowledge development practice in MBL environments, to determine the appropriateness of foregrounded focal ideas in the specific context in which they are being used (Lineback, 2015).

Because of the potential promise of redirection and the need to better understand and make explicit ways in which teachers can support student sensemaking and development of modeling competence in MBL environments, this chapter explores how teachers might be responsive to students' sensemaking with redirection in MBL environments.

12.2 Theoretical Perspectives

12.2.1 MBL Environments and Representations of Scientific Activity

MBL learning environments, for the purpose of this research, are defined in alignment with Louca and Zacharia (2012) as "an approach for teaching and learning in science whereby learning takes place via student construction of models as representations of physical phenomena" (p. 471). These environments are important in science education, since researchers like Manz (2015) point to the need for careful consideration of "what features of scientific activity systems situate the meaning of the practice in professional activity as well as whether and how we can represent those features in classroom environments" (p. 556). Given that Passmore, Gouvea and Giere (2014) note that science studies research has revealed how models serve as context dependent tools for organizing the day-to-day work of scientists, these features of scientific activity can be said to situate the meaning of practice in scientists' professional activity. Further, researchers have previously documented how models can serve as context dependent tools for organizing the day-to-day work of students across units of instruction in the service of representing scientific activity (e.g., Manz, 2015; Passmore et al., 2014; Stroupe, 2015). Here, scientific activity is understood in terms of activity theory (Vygotsky, 1978). More specifically, just as activity theory is concerned with the dialectic of subjects, tools, and objects in human pursuits (Roth & Lee, 2004), scientific activity is concerned with the dialectic of scientists, tools useful in scientific pursuits (e.g., science practices, disciplinary knowledge), and the objects of their pursuits (i.e., constructing and critiquing explanations of things that happen in the world (Ford, 2008)). Consequently, with MBL as one example of a representation of scientific activity in science classrooms, students (subjects) engage in developing and using models (tools) in concert with other science practices (e.g., engaging in argumentation) across an instructional unit to iteratively explain a unit anchoring phenomena (object) (Melville, Jones, & Campbell, 2017).

12.2.2 Modeling Competence

As alluded to earlier, the conception of modeling competence adopted in this chapter is aligned with the functional-pragmatic conception of competence (Klieme et al., 2008), whereby modeling competence can be understood as students' abilities to cope with challenges (e.g., explaining phenomena or solving problems) using modeling as an epistemic tool across a range of contexts (Chap. 1). In this conception, unlike decontextualized cognitive systems that are developed in isolated contexts and later deployed, competence is considered a context-specific ability that is sensitive to contextual demands and acquired by learners in situ (Klieme et al., 2008).

In Germany, competence models were adopted to take into account the shift in classrooms away from solely focusing on the acquisition of disciplinary science concepts to focusing more on the application of these concepts in meaningful contexts. In the U.S., this shift emphasizes the movement away from a focus in science classrooms on students 'learning about' disciplinary scientific concepts outside of meaningful contexts to a focus on students 'figuring out' how to use disciplinary science concepts and science practices to explain phenomena that happen in the world or to solve real world problems of consequence (Krajcik, 2015; NGSS Lead States, 2013). In this shift to 'figuring out' highlighted in the most recent U.S. standards documents, disciplinary scientific knowledge remains centrally important, however from the perspective of students its usefulness becomes apparent or functionally pragmatic in as much as it is helpful in explaining phenomena, generating new knowledge through predictions and investigations, and solving problems (Chap. 1). In addition, the focus on 'figuring out' in the newest standards documents has elevated the importance of science practices, like developing and using modeling competence being explored in this volume, as the tools students use to critique and refine explanations or solutions to problems as part of engaging in more authentic representations of scientific activity (Ford, 2015; Stroupe, 2015). Additionally and more specifically to the focus on modeling competence in this volume, the importance of developing students' modeling competence as a research tool is well aligned to the emphasis in the newest U.S. standards documents, especially since Chap. 1 reveals how modeling competence considers, among other things, the extent to which models "are used as tools in the acquisition of new insights" (p. 1) and reveals how "the goal . . . is to gain insightful knowledge with models" (p. 5).

In this chapter, the focus on student modeling competence was approached by examining a promising teacher-enacted methodological construct (i.e., redirection) that could potentially support the condition (i.e., an environment where ideas are foregrounded and scrutinized) under which student modeling competence might flourish. Such a condition, we postulate in alignment with others (Coffey, Hammer, Levin, & Grant, 2011; Lineback, 2015; Thompson et al., 2016), is one that takes into account the extent to which teachers are responsive to students' ideas and sensemaking practices and the relation of their ideas to disciplinary scientific ideas. Further, this positions students to coordinate their sets of ideas (Stewart, Cartier, & Passmore, 2005) to meet the cognitive demands of explaining a range of phenomena across contexts in more authentic or closer to 'real life' settings, so that student modeling competence is activated and further developed in situ (Koeppen, Hartig, Klieme, & Leutner, 2008).

12.2.3 Responsive Instructions and Redirection as a Responsive Methodological Construct

> The pedagogical task for teachers, then, is … to build upon students' initial ideas, partial understandings, and everyday experiences to support construction of on-going, evidence-based, and generalizable explanatory accounts of natural phenomena. (Thompson et al., 2016, p. 4)

This quote exemplifies the complex role of teachers in classrooms where supporting students in making progress connecting their ideas and experiences to developed and refined disciplinary science ideas over time is prioritized (Coffey et al., 2011). The growing body of research in science and mathematics education focused on understanding and supporting teachers' roles in recognizing, taking up, and assisting students in developing and critiquing theirs' and their peers' ideas over time is grounded in research such as teacher noticing (e.g., Sherin & van Es, 2005) and formative assessment (e.g., Ruiz-Primo & Furtak, 2007), and can be referred to as responsive instruction. Thompson et al. (2016) further connect responsive instruction to culturally responsive teaching (e.g., Gay, 2000), especially to the extent that it moves away from deficit framing of students' ideas, capabilities, and lived experiences. At the same time, responsive instruction presses against historical structural ways knowledge in classrooms is produced through classroom interactions in efforts to support more equitable opportunities for all students to participate. In other words, responsive instruction can be understood as providing students space and support to reason about phenomena or events that happen in the world by proposing their own ideas developed from prior experiences. Further, as part of responsive instruction, student ideas proposed as useful for reasoning about phenomena are subsequently foregrounded in discursive exchanges with peers and the teacher so that these ideas can be scrutinized and refined as they are connected with additional evidences and canonically relevant disciplinary science concepts.

However, as acknowledged by Lineback (2015), "[t]eachers are thereby placed in the rather challenging position of navigating among the various thoughts and viewpoints present, weighing the merits of pursuing one or more of those ideas and making a decision as to how to follow up those ideas in the moment during class" (p. 420). Given this, Lineback's work identified redirection as one responsive methodological construct that could be potentially useful for researchers and teachers alike for understanding how teachers navigated supporting student idea refinement in sensemaking classrooms.

Further, Lineback noted that to be considered a redirection, the teacher's attempt must communicate or provide the impression that a response from students is desired and space for that response be offered. Lineback identified two different types of redirection, an activity redirection and a focus redirection. The activity redirection can be understood as the teacher's bid to shift students from one activity to another (e.g., a discussion to designing an experiment), while the focus redirection can be understood as a teacher's attempt to shift the focus of students' attention from one scientific phenomenon or question to another. Each of these different types of redirection can be further nuanced according to Fig. 12.1 and it should be noted that Lineback reported that activity redirections occur less frequently and are easier to assess in terms of their presence in comparison to focus redirection. Finally, Lineback identified additional focus redirection codes that considered the extent to which and how the redirection was connected to students' comments (e.g., F_1-responsive directly connect to student idea(s) in previous exchange; F_2-delayed responsive disconnected from students' previous exchange, but revisited previously discussed phenomena, idea, or question).

Because of previous collaborations with the teacher in this research to explore and refine instructional approaches for supporting the development of student modeling competence within MBL environments (e.g., Campbell, Oh, & Neilson, 2013; Campbell & Neilson, 2009, 2012), as well as previous research demonstrating the teacher's developing facility engaging students in MBL environments (i.e. Campbell, Oh, & Neilson, 2012; Campbell, Zhang, & Neilson, 2011), we believed that closely examining this instruction using the redirection coding scheme could reveal informative strategies within the MBL environment that may have remained unnoticed.

Consequently, the following questions, focused this study:

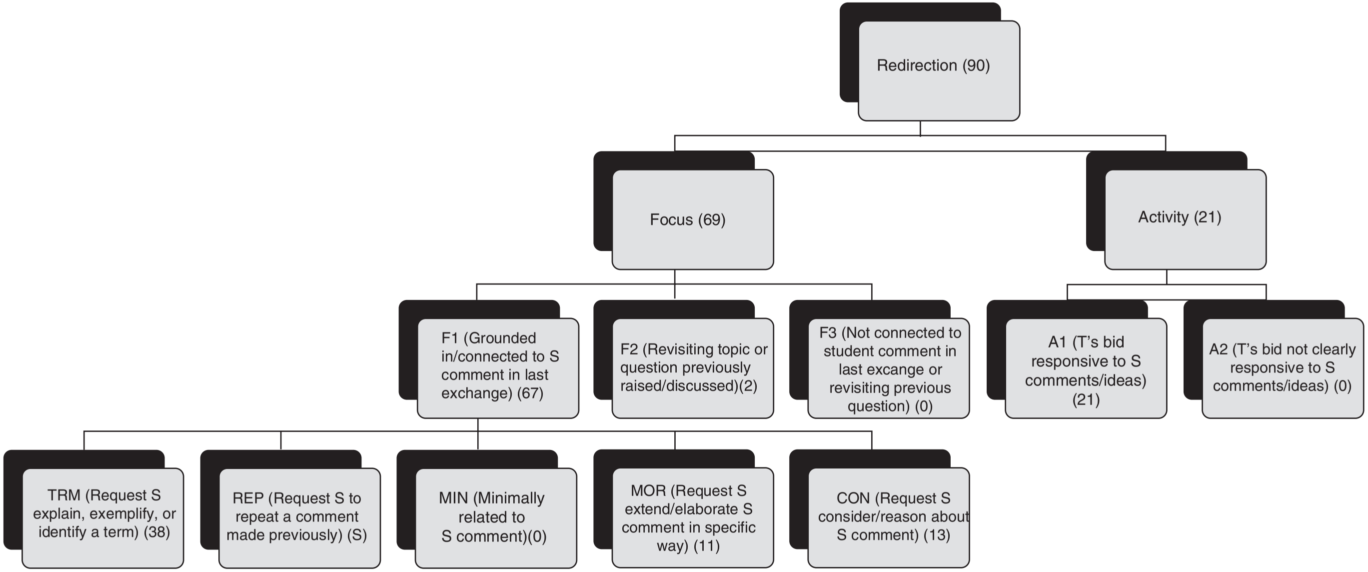

Fig. 12.1 Redirection Coding Scheme (adapted from Lineback, 2015). (Note: *T* Teacher, *S* Student, (#) Each Redirection Type Found)

1. To what extent and in what ways was redirection used as a responsive methodological construct in an MBL environment?
2. How can the use of redirection in an MBL environment be characterized?
3. What factors interact with a teacher's use of redirection within an MBL environment?

12.3 Methods

12.3.1 Context

The context of this investigation into the ways in which teachers might use a responsive methodological construct to support students' development of modeling competence in MBL environments was Mr. Bird's (pseudonym) physics classroom in the spring of 2013. Grades 10–12 students (age 15–18), with a few Grade 9 students (age 14–15), enrolled in this physics course. At the time of this data collection, Mr. Bird had taught physics for 15 years.

Mr. Bird collaborated extensively with the first author over the previous 7 years to develop MBL instructional units, refining them in response to classroom enactments, and working to understand their importance in science teaching and learning. More specifically, as the first author and Mr. Bird iterated over time how they planned units of instructions that constituted the MBL environment examined in this research they relied more generally on the Ambitious Science Teaching (AST) framework put forth by Stroupe and Windschitl (2015), whereby they (a) AST1-plan[ned] a unit around a "big science idea", (b) AST2-elicit[ed] and activat[ed] students' ideas about a puzzling phenomenon (for the purpose of adapting instruction), (c) AST3-help[ed] students make sense of science activities (with the aim of using science principles behind the selection of the activities to explain unit-anchoring phenomena), and (d) AST4-press[ed] students to construct evidence-based explanations" (p. 181).

Buoyancy was the focus of the MBL unit examined in this research, since it was believed to provide a context for applying Newton's Laws and supporting students in better understanding fluids. Figure 12.2 outlines the buoyancy unit investigated.

12.3.2 Data Collection and Analysis

Digital recordings of the five class periods served as the primary data for this research. All five class periods were transcribed so that both the recordings and transcripts could be used for analysis. An adapted version of Groenwald's (2004) phase strategy for explicating data was adopted for this research. In this, the first author completed the initial data coding and analysis, before the other three authors

Class period	Topic	Main activity	Instructional Purpose
1	Introduction to phenomena and initial explanatory models	Students discussed the phenomena, developed a ‘Gotta Have List’ and started development of initial explanatory models	Eliciting students initial ideas about the unit anchoring phenomena
2	Completed initial explanatory models and planned investigations to inform developing models	Students completed initial explanatory models, identified areas of their models that would benefit from additional evidence that could be gathered from investigations and planned investigations that could be carried out in the laboratory	Supporting students in identifying possible factors they thought would affect buoyancy
3 and 4	Laboratory investigations	Students completed design of investigations, carried out investigations in laboratory and prepared to share results of investigations in whole-class discussion	Investigating factors thought to affect buoyancy
5	Whole-class discussion of experimental findings	Students shared their experimental findings with the class in a whole-class setting.	Pressing students to share their laboratory findings and make sense of them in terms of how their findings might contribute to their evolving model of the unit anchoring phenomena

Fig. 12.2 Buoyancy unit

reviewed the coding in the context of transcripts. If disagreements or questions arose about a specific code or theme as the final three authors reviewed the first author’s coding in the context of the transcripts, the researchers revisited the original archived videos and student artifacts and sought consensus of interpretation before finalizing the codes and themes. Analysis proceeded through a recursive process where emergent findings were continually checked and revisited as new findings emerged until it was believed that consistency of interpretation was accomplished.

12.4 Findings

The findings are organized by the research questions and include relevant transcript excerpts from Mr. Bird’s classroom of evidence used for the claims presented.

1. *To what extent and in what ways was redirection used as a responsive methodological construct in an MBL environment?*

To answer the first question, a report of the general number and kinds of redirection instances found is shared. First, however the following is offered as one instance of redirection to provide a sense of what redirection looked like in Mr. Bird’s classroom:

Mr. Bird: *Buoyancy, that's a term that we haven't defined yet, so it worries me. You said—*

Student 1: *Floating … The ability of the object or something to float …*

Mr. Bird: *Can you have different degrees of buoyancy? If you sink, you're not buoyant, is that right? …*

Student 2: *I think there are different levels. Like, there can be something that just goes right to the bottom of whatever and stays there and will hardly move. Whereas, something else could bounce around I think, so it has the ability to move around, not just sink in water …*

Mr. Bird: *Tell me what happens when you get in water …*

Student 2: *Depends on who you are. Some people float, some people sink …*

Student 3: *You are going to float. Water pushes you up … Buoyancy would be how much the fluid pushes you up—if something's more buoyant, then the fluid will push it more. If it's less buoyant, the fluid won't push it as much*

Mr. Bird: *What if we say that's what buoyancy is there? It's the amount that water pushes you up.*

This instance of redirection occurred as the class was working to create a list of ideas that might be important when developing models to explain the three, related unit-anchoring phenomena. In this, when Mr. Bird found students frequently using the term buoyancy he redirected their attention to defining the term buoyancy, since it appeared that he did not yet feel comfortable that they were using the term in a consistent way. This example was coded as 'request[ing] the students consider/reason about student comment(s)' (i.e., F_1 CON). The other types of redirection identified can be found in Fig. 12.1.

Beyond these more general descriptors of the types of redirection reported in Fig. 12.1, it was noted that most of the ways that Mr. Bird interacted with students in the unit were characterized as redirection. Exceptions to this were minimal and included only when he introduced the demonstrations or phenomena on the first class period of the unit or outlined logistical directions to organize students' engagement in the unit either towards the beginning or end of each class period within the unit. This is perhaps most evident in the large number of instances of redirection (i.e., 90) found across the 5-class period unit.

2. *How can the use of redirection in an MBL environment be characterized?*

To answer this question, we examined more closely the types of redirection Mr. Bird used. Based on this, the following trends were noted: (a) F_1 TRM redirection was the most common type of redirection used across the unit and it was used almost exclusively on the final class period of the unit; (b) more variability in the types of redirection used occurred during Class Periods 1 and 2 compared to Class Periods 3–5; (c) activity redirection was used more during Class Periods 2–4 as students were identifying possible factors they thought affected buoyancy, carrying out investigations about these variables, and collecting data.

Notably, F_1 TRM redirection was widely used by Mr. Bird across the unit (i.e., 38/67 instances of redirection). As a reminder, this type of redirection was characterized as clearly grounded in or connected to student comments that emerged during the last exchange sequence that further requests students explain, exemplify, or identify a term. The fact that F_1 TRM redirection was so prevalent provides some insight into the responsive practices Mr. Bird used. In this, he was frequently found asking students to further explain their ideas or the basis of their claims. Additionally, as noted, Mr. Bird relied almost exclusively on this type of redirection in Class Period 5 of the unit with 22 instances of redirection identified and 18 of these being F_1 TRM redirection. Interestingly, the variability of the types of redirection Mr. Bird used across the unit decreased. This did not mean that less redirection was found later in the unit, since 22 instances of redirection were identified during Class Period 5 were comparable to the number of instances found in Class Periods 1 and 2 (i.e., 18 instances and 24 instances, respectively). Instead it merely signaled that there was more variability in the types of redirection used earlier in the unit. More specifically, Mr. Bird relied more on F_1 TRM type redirections in Class Periods 3–5, whereas earlier in the unit he relied on F_1 REP, F_1 MOR, and F_1 CON either more or equally compared to his use of F_1 TRM in the earlier class periods of the unit.

Lastly, activity redirection was used more during Class Periods 2–4 of the unit. These class periods coincided with the time students spent identifying possible factors students thought would affect buoyancy that would be tested in the laboratory as part of designing investigations and collecting data. The following is one example of an activity redirection from Class Period 4:

Mr. Bird: *I got a test for you. We got—I think it's a great test, but what would one of our controls have to be?*
Student 6: *The depth?*
Mr. Bird: *The depth. You guys need to get a big tote if you can find one.*
Student 7: *Like that?*
Mr. Bird: *Even bigger. We'll try and keep the depth, okay?*
Student 7: *Okay.*
Mr. Bird: *Okay, so let's clear this out of the way. The problem that we had before was that one floated, right? We need to figure out a way to measure the buoyant force and so we're gonna use this pulley to help us. Here's what I'm thinking. We could put this at the bottom and for—what we could do is we could see how much force it took to pull it under water and hold it under water, right? Then we'll know how much water's pushing up on it, right? It's gonna try and push it up. Let's see what kind of data we get.*
Okay, let's hook up our first object.

Prior to this episode the students and Mr. Bird recognized a flaw in how they had previously been collecting data in the laboratory to try to determine whether buoyant force changed as an object was submerged at increased depths in a liquid (i.e., water). This episode exemplifies how Mr. Bird was found making bids for students to change the activity they were doing based on issues he and the group discovered in a previous exchange. In this, it appeared as if he was using activity redirection as a means for helping students identify a different strategy other than what they may have thought of by themselves to pursue an idea they initially put on the table (i.e., that the depth an object is submerged in a liquid affects the amount of buoyant force on the object from the liquid).

3. *What factors interact with a teacher's use of redirection within an MBL environment?*

When considering what factors interacted with Mr. Bird's use of redirection, it was noted that an increased amount of redirection was used during Class Periods 1, 2, and 5 of the unit when compared to Class Periods 3 and 4. The decreased use during Class Period 3 might be attributed to a shortened class period in comparison to the other class periods, yet these trends also made sense in context with the different instructional purposes framed for each lesson explicated in Fig. 12.2. Redirection was found during Class Periods 3 and 4, but this occurred less often, mainly in small groups, and as a way for Mr. Bird to better understand how individual groups were thinking about buoyancy related to the laboratory investigations they had designed and were completing.

12.5 Discussion

At a time when increased attention has been given to supporting students' engagement in functionally pragmatic science practices including modeling competence, as is the focus of this volume, in the service of developing explanatory mechanistic accounts of real world phenomena, there is growing recognition of the need for increased attention to the role of teachers in such environments (Griesemer et al., 2016; Kahn, 2011; Manz & Renga, 2017; Schwarz et al., 2016). This research begins to address this need through revealing the extent and manner in which one teacher used redirection as a responsive methodological construct across an MBL instructional unit. In this section, we revisit our research questions to consider the extent to which our analysis of Mr. Bird's use of redirection revealed nuances of his responsive commitment to student idea refinement and how this commitment played out in terms of the transactional role he engaged in with students across the unit of instruction. We end the chapter considering potential implications of our analysis related to making more explicit the teacher's role in supporting students' development of functionally pragmatic modeling competence through redirection in MBL environments and additional research that may prove useful in building on what was learned in this research.

1. *To what extent and in what ways was redirection used as a responsive methodological construct in an MBL environment?*

Lineback (2015) proposed redirection as one methodological construct that might begin to characterize the role of teachers in responsive classrooms committed to student sensemaking. In this research within the MBL unit, redirection was found to be an important methodological construct for not only foregrounding ideas to help set the stage for agentic student pursuits during Class Periods 1 and 2 of the 5-class period unit, but also for helping them navigate investigations during Class Periods 3 and 4, and pressing them for evidence-based explanations in Class Period 5 of the unit. Evidence for this lies in how redirection was found as a mechanism that could, with the exception of logistical directions or what others have referred to as meta-talk (e.g., Campbell, Oh, & Neilson, 2013; Manz & Renga, 2017) be used early or later in each class period of the unit and be applied to characterize what Mr. Bird did throughout the unit. Researchers like, Thompson et al. (2016), point to how curriculum is necessary, but not sufficient for supporting rigor and responsiveness in science classrooms. In this, they suggested that "the interactions within the classroom are essential for sustaining the highest quality of scientific practice and sensemaking" (p. 52). In this research, the interactions that Mr. Bird engaged in with students within the classroom suggested possible mechanisms he used in his attempts to sustain the highest quality of scientific practice (i.e., students' iterative engagement in developing and using models across the unit) and sensemaking. Specifically, Mr. Bird relied on redirection, mainly in the form of focus redirection whereby he attempted to shift the focus of students' attention from one scientific phenomenon or question to another. And, as evidenced from a large majority of the types of redirection Mr. Bird used (i.e., 67 F_1 Focus Redirections, compared to 2 F_2 and no F_3 Focus Redirections), he was almost exclusively found shaping his response or the redirection he used in response to the ideas of students that emerged in the previous exchange.

When these findings are considered in context of the limited amount of other research on responsive instruction in classrooms with redirection more about Mr. Bird's use of redirection can be understood. More specifically, Lineback (2015) identified two different ways in which the same teacher was interacting with students in sample episodes she analyzed. In one episode, the teacher she followed prompted students to share their ideas, but was not found following up on her initial questions in ways that pressed students to elaborate on their thinking or to pursue a particular path of thinking, instead in this type of episode the teacher did not request that students respond to anything in particular that they or their peers may have said. Consequently, they were permitted to "take up any topic they wished", something that in the end resulted in "conversation[s] . . . meander[ing] without pushing her students to pursue any particular student's idea extensively" (p. 426). However, in other instances, Lineback found episodes where the teacher pursued "clarifications and/or elaboration from individual students on their own contributions" . . . she "actively encourage[d] her students to extend one another's comments" (p. 426). This second set of episodes characterized as the teacher asking for clarifications or elaborations, were more aligned with the responsive ways in which Mr. Bird was found helping students follow their lines of logic as a responsive form of instruction that was evidenced in the almost exclusive type of F_1 and A_1 types of redirection he used and the lack of F_3 and A_2 types of redirection.

2. *How can the use of redirection within an MBL environment be characterized?*
3. *What factors interact with a teacher's use of redirection in an MBL environment?*

Because the characterization of how redirection was believed to be intricately connected to the factors that interacted with Mr. Bird's use of redirection, the discussion of findings for these two research questions have been merged. Importantly the different activities planned for different purposes across the MBL unit contributed to the emergence of the characterizations of the use of redirection within an MBL unit, while also standing out as the most notable factor that interacted with the use of redirection in this current research. More specifically, as the first author and Mr. Bird iterated over time how they planned units of instructions that constituted the MBL environment examined in this research, they relied more generally on the Ambitious Science Teaching (AST) framework put forth by Stroupe and Windschitl (2015) described in more detail earlier. When this AST Framework was considered alongside the findings, a potential explanation for the emergent redirection trends surfaced. In the buoyancy unit examined in this research during Class Period 1 of the unit, Mr. Bird sought to elicit students' initial ideas for how they might explain the unit-anchoring phenomena. In this stage of the AST Framework (i.e., AST2, 2014a) there is a need for teachers to engage students in ways that will illuminate and help them understand the range of ideas, experiences, and language or ways of talking and thinking that students use in thinking about the anchoring phenomena (AST, 2014a). Class Periods 2–4 of the unit coincided with AST3 or the stage of the AST framework focused on helping students make sense of science activities. In this particular unit, Mr. Bird used Class Period 2 of the unit to draw on students' initial ideas. Students shared their models during Class Period 1 to identify factors within their initial models they proposed affected buoyancy as a focus of the activities that students engaged in during AST3. More specifically, in AST3 in this unit, students designed investigations that would allow them to collect data to determine whether or not their initial ideas were supported by evidence collected in the laboratory. This stage of the AST framework is intended to "help students develop new ideas to use in revising their explanatory models for the anchoring phenomena" (AST, 2014b, p. 1) and can involve activities that range from teacher demos to students designing their own study or working with second hand data. In this particular unit, as noted earlier, students designed their own investigations, carried them out, and used the emergent data as a mechanism for developing new ideas that were useful in revising their initial explanatory models. Finally, Class Period 5 of the unit aligned with AST4 of the AST framework. This stage of the AST framework, is designed to help students "rally different kinds of evidence in support of their culminating explanations" . . . during this stage they "construct and evaluat[e] claims" and "draw final ideas together in models and explanations" (AST, 2014c, p. 1). In

Class Period(s)	AST Framework	Types and Purpose of Redirection
1-2	AST2-Eliciting students' ideas	Ranging from F_1 TRM to F_1 MOR and F_1 CON to elicit the range of ideas students had about how to explain the anchoring phenomenon
3-4	AST3-Helping students make sense of science activities	F_1 TRM to get students to explain why they were doing the investigations they were doing or Activity Redirection (A_1) to make suggestions for changing the activity in which students were engaged if another activity thought more productive in helping students explain the anchoring phenomena
5	AST4- Pressing students to construct evidence-based explanations	F_1 TRM to ask students to explain something they said in a previous exchange at the end of the unit

Fig. 12.3 Unit class periods and AST framework connected to types of redirection used

the buoyancy unit, during Class Period 5 Mr. Bird invited students to share, in whole class discussion, their findings from their laboratory investigations with the aim of pressing them to articulate claims about their data that could be used in their final explanatory models.

Figure 12.3 provides an abbreviated summary of how the class periods of the unit connected to the AST framework and how this was found related to the types of redirection used that is further explicated next.

As can be seen in Fig. 12.3, as the different aims of the different stages of the AST framework were taken into account, some explanation for how Mr. Bird used redirection emerged. As an example, during Class Periods 1 and 2 of the unit, as revealed in the findings, more variability in the types of redirection used occurred. These were the class periods of the unit that were aligned with AST2, where Mr. Bird was trying to elicit the range of ideas students had about how to explain the anchoring phenomenon. During these class periods, he used far more different types of redirection ranging from F_1 TRM to F_1 MOR and F_1 CON. These were class periods that Mr. Bird was trying to elicit many ideas and support students in selecting among their ideas as they begin to design investigations to test their ideas as part of AST3. After Mr. Bird initially engaged to help shape their investigations during Class Period 2, students worked in the laboratory conducting their investigations during Class Periods 3 and 4 of the unit as part of AST3. During these class periods, he used F_1 TRM to get students to explain why they were doing the investigations they were doing or Activity Redirection (A_1) to make suggestions for changing the activity in which students were engaged if he believed another activity might be more productive in helping students explain the anchoring phenomena. An episode exemplifying this was shared earlier when Mr. Bird suggested students use a different experimental setup to examine an idea they initially put on the table (i.e., that the depth of an object submerged in a liquid affects the amount of buoyant force on the object from the liquid). Finally, during Class Period 5 of the unit, aligned with AST4, Mr. Bird relied mainly on F_1 TRM. While it is conceivable that other forms of redirection (e.g., F_1 MOR; F_1 CON) might also support extended turns in student discourse aimed at pressing students to construct evidence-based explanations, Mr. Bird’s use of F_1 TRM made sense within the purpose of AST4, whereby he was frequently found asking students to explain something they said in a previous exchange at the end of the unit. This occurred at a time when he was focused less on getting a wide range of student ideas on the table, as was his objective during Class Period 1 of the unit during AST2 when more variability in the types of redirection he used was found. At the end of the unit Mr. Bird, while committed to drawing on students’ ideas, as evidenced in the instances of redirection during Class Period 5 (i.e., 15 instances of redirection), was also focused on AST4, supporting the class in converging on a consensus model of those factors that affected buoyancy with the data they collected, so that these factors could be taken into account in final revisions to students’ final explanatory models.

12.6 Implications and Conclusion

New visions of teaching and learning outlined in national standards documents (e.g., NGSS Lead Stages, 2013; NRC, 2012) ask teachers to engage students in ways that are dramatically different than what has previously been done (NASEM, 2015; Reiser, 2013). Researchers, professional developers, and leaders will need to provide accounts of how this can look in classrooms and the roles teachers can take up to support student learning in contexts that more authentically represent scientific activity. The research conducted as part of this chapter provides the beginnings of such classroom accounts and the role one teacher took in supporting learners in an MBL environment, where models served as the context-dependent tools for supporting the everyday sensemaking work of students in the classroom. This is especially important as functional-pragmatic shifts toward developing students’ modeling competence to explain a range of phenomena is increasingly prioritized (NRC, 2012). To this end, we acknowledge that the teacher’~~s~~ classroom that was the focus of this chapter cannot be used to generalize about the extent to which or how other teachers facilitate instruction that is responsive to student idea refinement. However, it is believed that our close nuanced analysis and interpretation can begin to address the possible productive roles teachers can play in these learning environments, so that these environments are more conducive to developing student modeling competence.

Beyond what the unit has begun to contribute to the framework for modeling competence (Chap. 1) that served as the focus of this volume, this research suggested, in alignment with what others have noted (e.g., Thompson et al., 2016), that the curriculum, or in the case of this research, the framework used to shape curriculum is intricately entangled in the pedagogical role of the teacher, Mr. Bird, in learning environments. More, specifically related to this research, it became evident that the different types of redirection found were connected to the purposes of the different activities that were strategically planned as part of the unit, especially related to the ways in which the unit unfolded with respect to the iterative development of students’ models (i.e., eliciting students initial models, supporting the refinement of student models through investigations and whole class sensemaking). As alluded to earlier, Thompson et al. (2016) pointed to how curriculum is necessary, but not sufficient for supporting rigor and responsiveness in science classrooms. Based on this research, we might add this to point toward how responsive instruction is intricately bound up in curriculum or the intentions of the different activities within a curriculum framework. In fact, this research revealed how the AST framework, essentially a framework that supports students refinement of models across an instructional unit, appeared to serve as a compass for the teacher that led to the use of different forms of responsive instruction (i.e., different types of redirection). The specific forms of responsive instruction were likely not mapped out ahead of time, especially not at the grain size of the teacher committing to use F_1 TRM, as an example. Instead the AST framework and the subsequent unit and modeling focus throughout appeared to lead to a responsive commitment to student ideas and the emergent, instead of planned, use of the different forms of responsive instruction Lineback (2015) identified.

References

Ambitious Science Teaching. (2014a). *Teaching practice set: Eliciting students' ideas and adapting instruction*. http://uwcoeast.wpengine.com/wp-content/uploads/2014/08/Primer-Eliciting-Students-Ideas.pdf

Ambitious Science Teaching. (2014b). *Teaching practice set: Supporting on-going changes in student thinking*. http://uwcoeast.wpengine.com/wp-content/uploads/2014/08/Primer-Supporting-Changes-in-Thinking.pdf

Ambitious Science Teaching. (2014c). *Teaching practice set: Pressing for evidence based explanations.* http://uwcoeast.wpengine.com/wp-content/uploads/2014/08/Primer-Pressing-for-Explanations.pdf

Campbell, T., & Neilson, D. (2009). Student ideas and inquiries: Investigating friction in the physics classroom. *Science Activities: Classroom Projects and Curriculum Ideas, 46*(1), 13–16.

Campbell, T., & Neilson, D. (2012). Modeling electricity: Model-based inquiry with demonstrations and investigations. *The Physics Teacher, 50*, 347–350.

Campbell, T., Oh, P. S., & Neilson, D. (2012). Discursive modes and their pedagogical functions in model-based inquiry (MBI) classrooms. *International Journal of Science Education., 34*(15), 2393–2419.

Campbell, T., Oh, P. S., & Neilson, D. (2013). Reification of five types of modeling pedagogies with model-based inquiry (MBI) modules for high school science classrooms. In M. S. Khine & I. M. Saleh (Eds.), *Approaches and strategies in next generation science learning* (pp. 106–126). Hershey, Pennsylvania: IGI Global. https://doi.org/10.4018/978-1-4666-2809-0.ch006

Campbell, T., Zhang, D., & Neilson, D. (2011). Model based inquiry in the high school physics classroom: An exploratory study of implementation and outcomes. *Journal of Science Education and Technology, 20*(3), 258–269.

Coffey, J. E., Hammer, D., Levin, D. M., & Grant, T. (2011). The missing disciplinary substance of formative assessment. *Journal of Research in Science Teaching, 48*, 1109–1136.

Ford, M. (2008). 'Grasp of practice' as a reasoning resource for inquiry and nature of science understanding. *Science & Education, 17*, 147–177.

Ford, M. (2015). Educational implications of choosing "practice" to describe science in the next generation science standards. *Science Education, 99*(6), 1041–1048.

Ford, M. J. (2005). The game, the pieces, and the players: Generative resources from alternative instructional portrayals of experimentation. *Journal of the Learning Sciences, 14*(4), 449–487.

Ford, M. J., & Forman, E. A. (2006). Redefining disciplinary learning in classroom contexts. *Review of Research in Education, 30*, 1–32.

Gay, G. (2000). *Culturally responsive teaching: Theory, research, & practice*. New York: Teachers College Press.

Gouvea, J., & Passmore, C. (2017). Models of' versus 'models for'. *Science & Education, 26*(1–2), 49–63.

Griesemer, D., Lo, A. S., Guy, C. R., Harris, E., & Passmore, C. (2016). Successes and challenges in promoting student sense making in modeling classrooms. In C. Passmore (Chair) related paper set *Epistemic framing and agency modeling classrooms* conducted at the meeting of the National Association for Research in Science Teaching, Baltimore, MD.

Groenewald, T. (2004). A phenomenological research design illustrated. *International Journal of Qualitative Methods, 3*, 1), 1–1),25.

Khan, S. (2011). What's missing in model-based teaching. *Journal of Science Teacher Education, 22*, 535–560.

Klieme, Hartig, & Rauch. (2008). The concept of competence in educational contexts. In J. Hartig, E. Klieme, & D. Leutner (Eds.), *Assessment of competencies in educational contexts* (pp. 3–22). Göttingen, Germany: Hogrefe & Huber Publishers.

Koeppen, K., Hartig, J., Klieme, E., & Leutner, D. (2008). Current issues in competence modelling and assessment. *Zeitschrift für Psychologie / Journal of Psychology, 216*, 60–72.

Krajcik, J. (2015). Three-dimensional instruction: Using a new type of teaching in the science classroom. *The Science Teacher, 83*(8), 50–52.

Lehrer, R., & Schauble, L. (2006). Scientific thinking and science literacy: Supporting development in learning in contexts. In W. Damon, R. M. Lerner, K. A. Renninger, & I. E. Sigel (Eds.), *Handbook of child psychology* (Vol. 4, 6th. ed.). Hoboken, NJ: Wiley.

Lineback, J. E. (2015). The redirection: An Indicator of how teachers respond to student thinking. *The Journal of the Learning Sciences, 24*(3), 419–460. https://doi.org/10.1080/10508406.2014.930707

Louca, L. T., & Zacharia, Z. C. (2012). Modeling-based learning in science education: Cognitive, metacognitive, social, material and epistemological contributions. *Educational Review, 64*(4), 471–492.

Manz, E. (2015). Representing student argumentation as functionally emergent from scientific activity. *Review of Educational Research, 85*(4), 553–590.

Manz, E., & Renga, I. P. (2017). Understanding how teachers guide evidence construction conversations. *Science Education, 101*, 584–615.

Melville, W., Jones, D., & Campbell, T. (2017, September). *Building the science department*. Arlington, VA: National Science Teachers Association Press.

National Academy of Sciences, Engineering, and Medicine [NASEM]. (2015). *Science teachers' learning: Enhancing opportunities creating supportive contexts*. Committee on strengthening science education and teacher advisory council, division of behavioral and social science education. National science education standards. Washington, DC: The National Academy Press.

National Research Council [NRC]. (2012). *A framework for K-12 science standards: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academy of the Sciences.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: National Academies Press.

Passmore, C., Gouvea, J. S., & Giere, R. (2014). Models in science and in learning science: Focusing scientific practice on sense-making. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 1171–1202). Dordrecht, The Netherlands: Springer.

Pickering, A. (1995). *The mangle of practice: Time, agency, and science*. Chicago: University of Chicago Press.

Reiser, B. J. (2013). *What professional development strategies are needed for successful implementation of the next generation science standards?* Paper presented at the Invitational

Research Symposium on Science Assessment, ETS, Washington, DC. Retrieved from http://www.k12center.org/rsc/pdf/reiser.pdf

Roth, W.-M., & Lee, S. (2004). Science education as/for participation in the community. *Science Education, 88*, 263–291.

Rouse, J., (2007). Practice theory. *Division I Faculty Publications* (Paper 43). Retrieved from http://wesscholar.wesleyan.edu/div1facpubs/43

Ruiz-Primo, M. A., & Furtak, E. M. (2007). Exploring teachers' informal formative assessment practices and students' understanding in the context of scientific inquiry. *Journal of Research in Science Teaching, 44*(1), 57–84.

Sandoval, W. A. (2015). Epistemic goals. In R. Gunstone (Ed.), *Encyclopedia of science education* (pp. 393–398). Dordrecht, The Netherlands: Springer.

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In B. Smith (Ed.), *Liberal education in a knowledge society* (pp. 67–98). Chicago: Open Court.

Schwarz, C., Calabrese Barton, A., Tzou, C. T., Colley, C., Warren, B., … Haverly, C. (2016). *Science learning contexts, characteristics, and activities*. Symposium conducted at the meeting of the National Association for Research in Science Teaching, Baltimore, MD.

Sherin, M. G., & van Es, E. A. (2005). Using video to support teachers' ability to notice classroom interactions. *Journal of Technology and Teacher Education, 13*, 475–491.

Stewart, J., Cartier, J. L., & Passmore, C. M. (2005). Developing understanding through model-based inquiry. In S. Donovan & J. Bransford (Eds.), *How students learn* (pp. 515–565). Washington, DC: National Academies Press.

Stroupe, D. (2014). Examining classroom science practice communities: How teachers and students negotiate epistemic agency and learn science-as-practice. *Science Education, 98*(3), 487–516.

Stroupe, D. (2015). Describing "science practice" in learning settings. *Science Education, 99*(6), 1033–1040.

Stroupe, D., & Windschitl, M. (2015). Supporting ambitious instruction by beginning teachers with specialized tools and practices. In J. Luft & S. Dubois (Eds.), *Newly hired teachers of science: A better beginning* (pp. 181–196). Amsterdam: Sense Publisher.

Thompson, T., Hagenah, S., Kang, H., Stroupe, D., Braaten, M., Colley, C., et al. (2016). Rigor and responsiveness in classroom activity. *Teachers College Record, 118*(5), 1–58.

Vygotsky, L. S. (1978). *Mind and society: The development of higher mental processes*. Cambridge, MA: Harvard University Press.