

**A Mixed-Methods Exploration of Mastery Goal Support in 7<sup>th</sup>-Grade Science Classrooms**

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### **Abstract**

Mastery goal structures, which communicate value for developing deeper understanding, are an important classroom support for student motivation and engagement, especially in the context of science learning aligned with the Next Generation Science Standards. Prior research has identified key dimensions of goal structures, but a more nuanced examination of the variability of teacher-enacted and student-perceived goal structures within and across classrooms is needed. Using a concurrent mixed-methods approach, we developed case studies of how three 7th-grade science teachers enacted different goal structures while teaching the same chemistry unit and how their students perceived these goal structures. Student perceptions were largely consistent with our observational analysis and suggested that a positive social climate and autonomy support are important elements of mastery goal structure. However, balancing socio-emotional support with sufficient academic rigor may be especially important for students with high levels of mastery goal orientation and self-efficacy in science. Implications for research include the need for further research linking classroom stimuli to variability in perceived goal structure, especially across students with different motivational characteristics. Implications for practice include strategies for science teachers to promote perceptions of a mastery goal focus in students, particularly through feedback and recognition practices.

*Keywords:* motivation and engagement; science education; achievement goal theory; mixed methods research; case study

### **A Mixed-Methods Exploration of Mastery Goal Support in 7<sup>th</sup>-Grade Science Classrooms**

Achievement goal theory (AGT) highlights the importance of creating classroom goal structures to support mastery goals, which focus on developing competence, rather than performance goals, which focus on demonstrating competence (Ames, 1992). Theory and prior research have identified important dimensions of goal structures within classrooms that communicate to students the relative valuation of mastery versus performance goals (Ames, 1992; Patrick et al., 2001), but relatively little work to date has provided a suitably nuanced examination of the specific teaching decisions that yield different goal structures (Urdan & Kaplan, 2020), or of the within-classroom and daily variability in how students perceive the teacher's level of support for mastery (Deemer, 2004; Kaplan et al., 2002). It is important to address this gap in the literature because prior research shows that goal structures have an impact on students' motivation and that these processes are dynamic and complex (Murayama & Elliot, 2009). In this study, we used a novel mixed-methods approach to target these gaps in the AGT scholarship by foregrounding a qualitative analysis of classroom goal structures and pairing the ensuing case narratives with quantitative reports of students' daily perceptions to capture the nuanced relations between teachers' practices and students' experience.

We investigated these goal structures in the context of middle school science instruction. Mastery goals may be especially important for students' engagement in science classrooms given the conceptual shifts in science education in the United States promoted by the Framework for K-12 Science Education (National Research Council, 2012) and the Next Generation Science Standards (NGSS; NGSS Lead States, 2013), which emphasize scientific sense-making and problem solving. However, despite the prominent overlap between mastery goals and effective engagement in science learning (Kubsch et al., 2020; Radoff et al., 2019), few studies have

explicitly examined AGT in the context of NGSS implementation. Additionally, prior research has suggested that students may perceive less support for mastery goals from their middle school STEM teachers compared to their elementary teachers, influencing their self-efficacy in these fields (Friedel et al., 2010). We therefore aimed to provide a stronger understanding of how middle school science teachers can support students' mastery goal orientation, facilitating the effective implementation of NGSS instruction and deeper learning in science.

### **Background**

AGT is a framework for understanding student motivation through the purposes and meanings that students ascribe to engaging in achievement-related behaviors—i.e., their personal achievement goals (Ames, 1992; Dweck & Leggett, 1988; Maehr & Midgley, 1991; Nicholls, 1984). Achievement goals interact with other motivational beliefs, such as self-efficacy, to predict students' behavior in achievement situations, but contextual factors in the environment can reciprocally influence students' endorsement of different achievement goals. The educational cultures of schools and classrooms are thought to shape students' adoption of achievement goals by establishing goal structures that convey explicit and implicit messages to students about the purpose of engaging in academic tasks (Ames, 1992). Furthermore, students' personal achievement goals may influence classroom goal structures because they contribute to an overall classroom culture (Urdan, 2004a). An important aim of AGT research is to understand how classroom goal structures are related to students' personal achievement goals and to understand how students perceive motivational characteristics of their classrooms (Brophy, 2005; Lau & Nie, 2008; Scherrer et al., 2020).

### **Personal Achievement Goal Orientations**

AGT distinguishes between *mastery goal orientations* and *performance goal*

*orientations*. Individuals with a mastery goal are motivated by the prospect of developing greater competence, new skills, and deeper understanding; they judge their academic performance by either a task-referenced standard, such that external criteria delineate different levels of mastery, or an intrapersonal standard, comparing current performance to their own past performance (Ames, 1992). By contrast, individuals with performance goals focus on *demonstrating* competence, which often involves social comparison and normative standards of achievement because the main purpose of engaging in learning tasks is to attain a sense of one's ability relative to others (Midgley et al., 2001). Work by Elliot (1999) and others subsequently distinguished between individuals' motive to *approach* the successful accomplishment of a personal achievement goal, or to *avoid* failure in achieving the goal. These valences are commonly used to differentiate the self-worth-preserving motives of performance goals (Urdan & Kaplan, 2020): an individual with performance-approach goals is motivated primarily to outperform others because this affirms their self-concept of ability (Ames, 1992), whereas individuals who endorse performance-avoidance goals want to avoid looking less capable than others (Elliot, 1999). Although some work has discussed mastery-avoidance goals (Elliot, 1999; Pintrich, 2000), generally the literature focuses on mastery-approach goals (Scherrer et al., 2020; Wormington & Linnenbrink-Garcia, 2017), referred to subsequently in this paper as mastery goals.

Research on the relation between motivational outcomes and personal achievement goals has generally identified positive associations with mastery goals, negative associations with performance-avoidance goals, and mixed findings with performance-approach goals. Prior research has linked mastery goals with a willingness to take risks and embrace challenging work, positive attitudes toward learning, and achievement-related behaviors such as time on task,

persistence, and use of learning strategies (Ames, 1992; Dweck & Leggett, 1988; Elliot & Hulleman, 2017). Performance-avoidance goals have been associated with negative affect following failure and behaviors such as avoiding challenge, use of superficial learning strategies, and cheating (Butler & Shibaz, 2008; Elliot & Hulleman, 2017; Lau & Nie, 2008; Urdan et al., 2002). In some studies, performance-approach goals were correlated with problematic achievement behaviors like test anxiety and avoidance of help-seeking (Huang, 2011; Linnenbrink-Garcia et al., 2008; Middleton & Midgley, 1997; Senko et al., 2011), but in others they correlated with achievement outcomes and with positive achievement behaviors like valuing of academic work and effort (Midgley et al., 2001; Senko et al., 2013). These mixed findings may relate to the different motivational patterns that stem from students pursuing multiple goals simultaneously (Senko et al., 2012). For example, some studies have suggested that performance-approach goals are associated with more positive outcomes when individuals also endorse mastery goals (Wormington & Linnenbrink-Garcia, 2017).

The relation between personal achievement goals and motivational and achievement outcomes may also vary across different levels of self-efficacy, or an individual's belief in their ability to perform a task successfully (Bandura, 1977). Since the inception of AGT, individuals' self-efficacy has been theorized to moderate the association between performance goal orientations and behavioral outcomes, such that performance goals are especially detrimental for students with low self-efficacy (Ames, 1992; Dweck & Leggett, 1988). Although this moderation pattern has been inconsistently replicated in empirical research (Elliot, 2005; Midgley et al., 2001), the potential relation between self-efficacy and self-worth preserving motives makes self-efficacy an important construct to consider alongside personal achievement goals in AGT work (Friedel et al., 2010; Urdan & Kaplan, 2020).

### Classroom Goal Structures

AGT assumes that the structure of a learning context helps to shape students' personal achievement goals and, in turn, their academic behaviors (Ames, 1992). Due to both the mixed findings about performance goal outcomes and the prevalence of existing educational structures that promote normative comparison and competition (Midgley et al., 2001), goal theorists have generally recommended that schools and teachers seek to emphasize mastery goals (i.e., implement mastery goal structures) and downplay performance goals (Brophy, 2005; Ciani et al., 2010; Wormington & Linnenbrink-Garcia, 2017). Prior work has shown mastery goal structures to be characterized by appropriately challenging work; support for student autonomy; feedback and evaluation focused on objective standards, effective strategy use, and self-improvement rather than competition; and a positive social climate, including non-competitive or comparative grouping practices and adaptive messaging around failure and mistakes (Anderman et al., 2002; Church et al., 2001; Ciani et al., 2010; Koenka et al., 2019; Linnenbrink, 2005; Mueller & Dweck, 1998; Patrick et al., 2001, 2002, 2016; Rattan et al., 2012; Turner et al., 2002; Urdan & Schoenfelder, 2006). These features have been summarized through the acronym TARGET (task, authority/autonomy, recognition, grouping, evaluation, and time) and three additional categories: the social climate of the classroom, help-seeking behaviors, and general messages about ability, effort, challenge, and failure (Patrick et al., 2001; see Table 1).

**Table 1**

*Summary of Observation Categories (TARGET + 3) and Alignment with Instructional Design Elements for the NGSS.*

| Category | Key Influences | NGSS Instructional Design Elements |
|----------|----------------|------------------------------------|
|----------|----------------|------------------------------------|



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|                        |                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Task                   | <ul style="list-style-type: none"> <li>– Variety/differentiation; products, materials, procedures; participation structure</li> <li>– Purpose/rationale</li> <li>– Challenge/academic press</li> <li>– Scaffolds/learning strategies</li> <li>– Teacher affect toward task</li> <li>– Student affect toward task</li> </ul> | <ul style="list-style-type: none"> <li>– Differentiation for students who need more support or have already met expectations<sup>1</sup></li> <li>– Scaffolds and gradually adjusted supports over time<sup>2</sup></li> <li>– Lessons focused on making sense of something, with purpose understood by students<sup>2</sup></li> <li>– Active student engagement in figuring out scientific phenomena or solving design problems<sup>1</sup></li> </ul> |
| Authority/<br>Autonomy | <ul style="list-style-type: none"> <li>– Classroom management approaches</li> <li>– Opportunities for student autonomy (especially cognitive autonomy)</li> </ul>                                                                                                                                                           | <ul style="list-style-type: none"> <li>– Student co-creation of questions and plan to figure them out<sup>2</sup></li> </ul>                                                                                                                                                                                                                                                                                                                             |
| Recognition            | <ul style="list-style-type: none"> <li>– Patterns of recognition: individual vs. group, academic vs. behavioral, valence of recognition (positive, negative, neutral/unclear), public vs. private</li> <li>– Social comparison</li> </ul>                                                                                   | <ul style="list-style-type: none"> <li>– Ongoing feedback focused on learning<sup>2</sup></li> </ul>                                                                                                                                                                                                                                                                                                                                                     |
| Grouping               | <ul style="list-style-type: none"> <li>– Number and composition of student groups</li> <li>– Teacher talk about group composition/group roles</li> </ul>                                                                                                                                                                    | <ul style="list-style-type: none"> <li>– Students work together, critique each other's ideas, reach consensus<sup>2</sup></li> </ul>                                                                                                                                                                                                                                                                                                                     |
| Evaluation             | <ul style="list-style-type: none"> <li>– Administration of/reference to formal evaluation (e.g., tests, quizzes, graded homework)</li> <li>– Normative comments about what students "should/shouldn't" know</li> </ul>                                                                                                      | <ul style="list-style-type: none"> <li>– Evaluation embedded in instruction through elicitation of observable evidence of learning<sup>1</sup></li> </ul>                                                                                                                                                                                                                                                                                                |
| Time                   | <ul style="list-style-type: none"> <li>– Time breakdowns of class activities</li> <li>– References to time (e.g., time limits, time checks, expected pace of work)</li> </ul>                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Social                 | <ul style="list-style-type: none"> <li>– Teacher messaging about peer interactions</li> <li>– Nature of peer interactions, including conflict</li> </ul>                                                                                                                                                                    | <ul style="list-style-type: none"> <li>– Students sharing and explaining their ideas<sup>1</sup></li> <li>– Working together to build understanding<sup>2</sup></li> </ul>                                                                                                                                                                                                                                                                               |

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|                  |                                                                                                                                                                                                                                                                     |
|------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                  | <ul style="list-style-type: none"> <li>– Nature of teacher-student interactions, including conflict</li> <li>– Teacher rapport-building strategies</li> </ul>                                                                                                       |
| General Messages | <ul style="list-style-type: none"> <li>– Messages related to success/failure, ease/difficulty, effort and strategy use, risk-taking, responding to challenge</li> <li>– Messages related to science</li> <li>– Teacher modeling mastery goal orientation</li> </ul> |
| Help             | <ul style="list-style-type: none"> <li>– Nature of student help-seeking behavior</li> <li>– Teacher messages about how students can get help</li> </ul>                                                                                                             |

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*Note.* Analogs for the Time, General Messages, and Help categories were less explicit in NGSS instructional design materials.

<sup>1</sup> These elements come from the Educators Evaluating the Quality of Instructional Products (EQuIP) rubric (NextGenScience, 2021).

<sup>2</sup> These elements come from Schwarz et al. (2017).

Goal structure research to date has predominantly drawn on student perceptions of goal structures and teaching practices at single time points and with limited observational components (see Meece et al., 2006 for a review). Other researchers have used survey data to categorize classrooms as high or low in mastery or performance goal structure and subsequently conducted qualitative analysis on various classroom components. In an influential work on goal structures, Patrick et al. (2001) used student survey data to identify four classrooms with different motivational “profiles” of goal support: high mastery, low performance; low mastery, high performance; high all; low all. Their subsequent development and use of the TARGET+3 framework to conduct classroom observations and analyze instructional patterns across the four focal classrooms contributed to foundational understanding of the classroom practices associated with student perceptions of mastery and performance goal structures. In a similar approach,

Morrone et al. (2004) used student surveys and end-of-semester course evaluations to confirm the mastery supportive structures in a college mathematics course before performing discourse analysis on class recordings to identify patterns in mastery-supportive classroom talk, such as press for understanding and non-evaluative recognition patterns.

Although these approaches have identified and clarified associations between certain classroom practices and students' perceptions of goal structure and endorsement of personal achievement goals across classrooms, the historical and continued reliance on quantitative survey data to select and categorize classrooms for further goal structure analysis inherently attenuates variations within classrooms, thereby creating a research base grounded in archetypal goal structures rather than rich description of "authentic contexts" (Urdan & Kaplan, 2020).

Observational studies of classroom practice using other frameworks have suggested that, rather than sorting easily into high or low quality, most teachers are somewhere in the middle, either because they use an assortment of teaching practices that fall at different points along a high/low continuum (Sun, 2018) or because their implementation of high-quality practices is modest or intermittent (Litke, 2020). Thus, the research designs typically employed in contemporary goal structure research may limit researchers' ability to capture the everyday complexities of classrooms that could pose challenges for teachers attempting to implement a mastery goal structure (Anderman & Klassen, 2015). A grounded, qualitative-oriented approach is needed to identify actionable areas for growth and to add to the knowledge base of classrooms.

Additionally, while student perception data are key to AGT research, prior research has not adequately explored the within-classroom variability in students' perceptions of goal structure at multiple time points or across students with different motivational characteristics. Exploring this variability is important, especially because students can have divergent

interpretations of the same teaching practices (Kaplan et al., 2002; Urdan, 2004b). Recent work on goal structures suggests that there is not a monolithic classroom-level goal structure that unidirectionally shapes students' personal goal orientations. Instead, students' personal achievement goal orientations contribute to their perceptions of teacher behaviors and their preferences for instructional styles (Senko et al., 2012), which in turn potentially impact their perception and interpretation of the classroom goal structure. For example, prior research has found evidence of a “match” or “mismatch” between classroom-level goals and student-level goals depending on each student's unique goal orientations (Murayama & Elliot, 2009). In turn, students' perceptions of the learning environment could influence their academic behaviors and potentially alter the goal structure as teachers respond to various levels of student engagement. Prior studies found that classroom goal structure components moderated the association between students' personal achievement goals and their motivation and achievement outcomes (Lau & Nie, 2008) or identified a complex interplay between personal achievement goals, other individual motivational factors such as mindset, and the learning environment (Mammadov & Hertzog, 2021). More nuanced examinations of within-classroom variations in student perceptions of goal structure would help teachers develop strategies to better meet the motivational needs of all students in a class.

### **Personal Achievement Goals and Classroom Goal Structures in Science Education**

Creating classroom goal structures that promote mastery goals is particularly important for science teachers working to implement the NGSS, which reflect a vision for science education centered on authentic problem-solving and developing deep understanding of scientific concepts (National Research Council, 2012; NGSS Lead States, 2013). This focus on developing scientific understanding and competence is consistent with a mastery goal orientation and

represents a deliberate shift away from the rote learning of textbook facts and formulas that tend to foster performance goals by emphasizing the demonstration of competence over deep understanding. Subsequent to the publication of the NGSS, science education researchers and educators have described curricular and instructional design elements for teaching the NGSS (NextGenScience, 2021; Schwarz et al., 2017) that align with the TARGET+3 framework for mastery goal structure (Table 1). For example, the NGSS emphasize assessment embedded in regular instruction and knowledge-in-use, or the ability to apply scientific knowledge across multiple real-world contexts, rather than traditional standalone assessments that may demand only shallow processing of content and make normative performance salient to students (Harris et al., 2019; Penuel et al., 2019). NGSS-aligned assessment includes opportunities for frequent practice and feedback to focus students on their developing scientific competence (Pellegrino et al., 2014), reflecting a mastery goal approach to science learning.

Prior research has also shown that science teaching practices that reflect the NGSS vision overlap with characteristics of mastery goal structure and contrast with performance goal structures. For example, the NGSS emphasize collaborative learning and the value of multiple perspectives in a community of scientific thinkers (Kolonich et al., 2018), stances that are inconsistent with the social comparison and competition inherent in performance goals (Rogat & Linnenbrink-Garcia, 2019). NGSS instruction encourages students to work together and share knowledge to develop deeper understanding, not compete for better grades or relative standing in the class. This shift away from concern about being correct toward sense-making and embracing challenge is a critical part of epistemological development in science learning (Radoff et al., 2019). More broadly, studies of effective science teaching have emphasized the importance of making time for students to engage in sense-making discussions (Conlin & Scherr, 2018) and

supporting students' cognitive autonomy in argumentation, discussion, and explanation (Larrain et al., 2019; Tang, 2020), practices that are consistent with mastery-supportive practices in the TARGET+3 framework.

However, little research has explicitly applied AGT to NGSS implementation. One study found that students who endorsed mastery goals were more effective at organizing and transferring knowledge to demonstrate knowledge-in-use consistent with the NGSS (Kubsch et al., 2020). Smart (2014) found that perceptions of teaching practices influenced middle school students' mastery goal orientation in science, value for learning science, and self-efficacy in science; however, the analysis of perceived teaching practices was not specifically grounded in an AGT perspective. Applying the AGT goal structure framework to science classrooms would strengthen understanding of how science teachers can create classroom goal structures that are perceived by multiple students as mastery-supportive and promote the adoption of mastery goals in service of NGSS alignment and deeper science learning. Such work would enhance the implementation of NGSS and contribute to knowledge in both motivation research and science education.

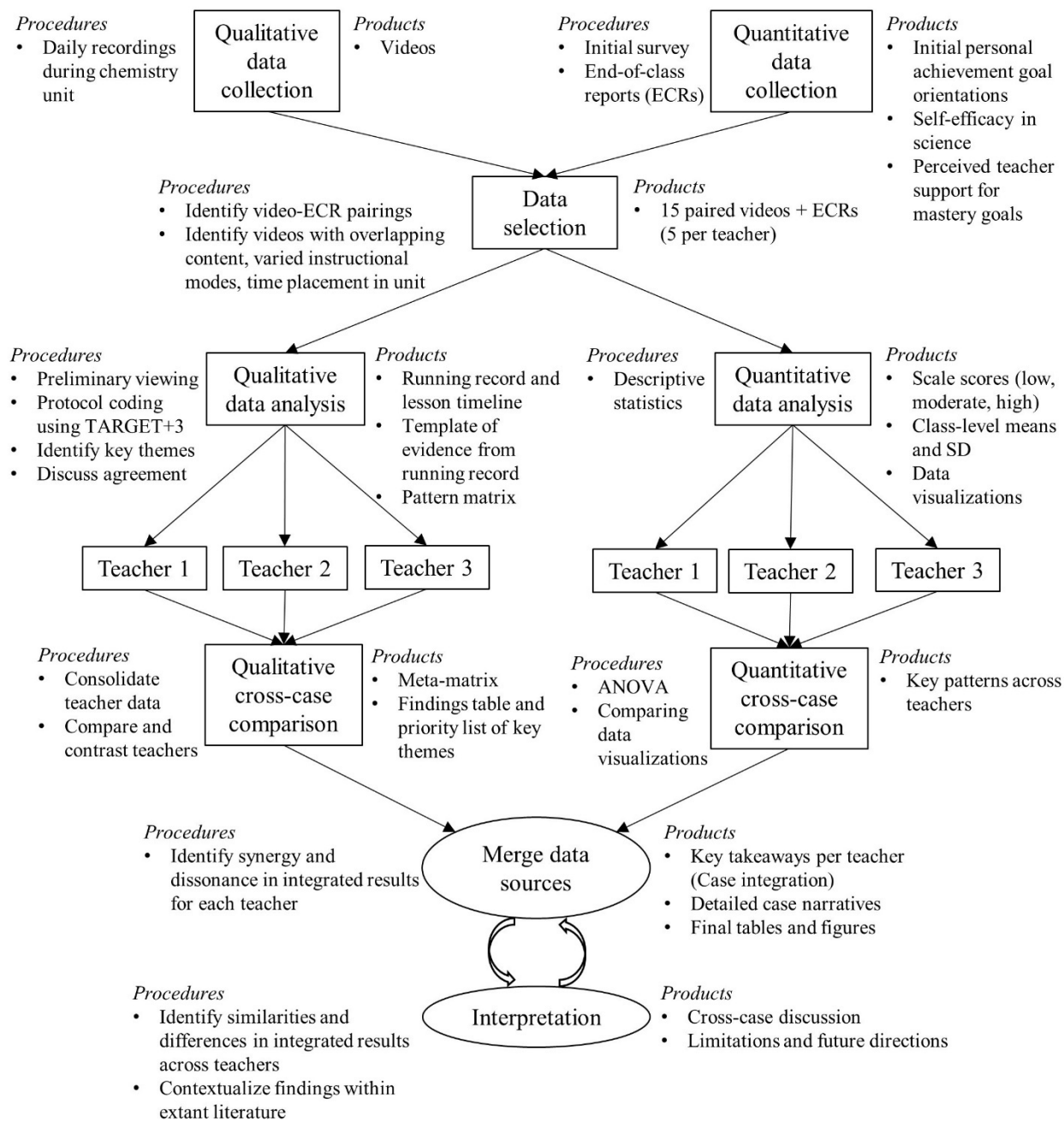
### **The Present Study**

We aimed to describe the classroom goal structures of three middle school science teachers implementing the same NGSS-aligned curriculum and to identify patterns in students' perceptions of their teacher's support for mastery goals within each classroom. To do this, we conducted a multiple-case study (Yin, 2009) using a convergent mixed-methods approach (Creswell, 2015; Johnson & Onwuegbuzie, 2004), in which quantitative analysis of student survey data complemented the qualitative analysis of observation data. Figure 1 diagrams the procedures constituting our convergent design, described in further detail under Method. Our

design was distinct from the sequential approach more typical of goal structure research, which relies on quantitative data to select, describe, and/or define classroom goal structures prior to any qualitative analysis. A convergent mixed-methods case study approach afforded the opportunity to use qualitative methods to provide rich, nuanced descriptions of teachers' practices while retaining traditional student survey approaches and commonly used AGT measures to capture students' perceptions of those practices.

**Figure 1**

*Procedural Diagram of Convergent Mixed-Methods Study Design*



*Note.* Diagram elements and design adapted from Creswell (2015).

Moreover, instead of using a sequential design to select teachers for qualitative analysis based on quantitative results, our case sampling method relied on common curriculum, allowing us to focus on the teachers' individual decisions and instructional approaches as differentiating features of their classroom goal structures. This afforded the opportunity to build a theoretical



and practical understanding of the pedagogical methods available to teachers to promote mastery goal structure in their classrooms, independent of the source curriculum. It also extended prior goal structure research by testing whether the relation between student perceptions of mastery goal support and mastery-supportive classroom practices identified by theory and research could be replicated when explored more inductively, rather than in pre-selected high- or low-mastery classrooms.

Finally, our convergent case study approach allowed us to focus on within-classroom variations in perceived mastery goal support among students with different motivational characteristics, as well as day-to-day variations in students' perceptions of mastery goal support from the same teacher. In doing so, we aimed both to extend the scholarly knowledge base on the variability of perceived mastery goal structure and to identify practical implications for teachers in how to promote mastery goals among students with diverse motivational characteristics and with consistency from day to day.

Thus, the following questions guided our inquiry:

1. How do teachers enact different goal structures while teaching lessons from the same curriculum?

Within each classroom...

2. Do students perceive different levels of mastery goal structure across these lessons?
3. Do student perceptions of mastery goal structure vary by students' personal goal orientations and self-efficacy?
4. What characterizes lessons that yield high or low student perceptions of mastery goal structure?

## Method

### Sample

Our participants were three 7<sup>th</sup>-grade science teachers who taught in public middle schools in a Midwestern state. Joanne<sup>1</sup> and Steve taught at School A while Sandra taught at School B in a different district in the same county. The two schools had students with similar socioeconomic backgrounds as indicated by free or reduced-priced lunch (FRPL) eligibility (School A: 64%; School B: 66%). However, the students at each school differed in racial demographics (School A: 59% non-Hispanic White; School B: 95% students of color, primarily Black) and percentage of English Language Learners (School A: 32%, School B: <5%). Joanne and Steve identified as White, and Sandra identified as Black. All three teachers were in their 50s, held master's degrees, and had been teaching for at least 15 years. Table 2 provides additional information about the teachers and data collection in each classroom.

**Table 2**

*Teacher Background Characteristics and Implementation Overview*

| School                             | School A              |                      | School B             |
|------------------------------------|-----------------------|----------------------|----------------------|
| Teacher                            | Joanne                | Steve                | Sandra               |
| Bachelor's degree field            | Elementary Education  | Chemical Engineering | Business             |
| Master's degree field              | K-8 Science Education | Education            | Elementary Education |
| Total years of teaching experience | 25                    | 24                   | 15                   |
| Years teaching at current school   | 20                    | 24                   | 1.5                  |

<sup>1</sup> All participant names are pseudonyms.

|                                             |               |               |               |
|---------------------------------------------|---------------|---------------|---------------|
| Student survey date                         | Dec. 10, 2019 | Dec. 10, 2019 | Nov. 15, 2019 |
| Implementation unit start date              | Jan. 7, 2020  | Jan. 7, 2020  | Dec. 3, 2019  |
| Total videos available                      | 27            | 25            | 21            |
| Total end-of-class reports (ECRs) available | 12            | 12            | 11            |

*Note.* All information reflects teacher responses in the summer prior to implementation.

The teachers were nominated by their district-level science coordinators to participate in professional learning (PL) on motivationally supportive instruction in the summer of 2019. Teachers were introduced to the main principles of AGT, among other motivation theories, and learned about instructional strategies aligned with mastery goal structure. For the 2019-20 school year, the teachers were asked to try implementing motivationally supportive strategies during one instructional unit and to attend periodic reflection meetings in which they received feedback from researchers. Thus, our participants were distinct from typical teachers in that they received some training and feedback on their support for student motivation. However, given that they were not pre-selected on the basis of their existing classroom goal structures, and all received the same “treatment,” we were still able to investigate our research question comparatively across the classrooms. The case narratives note instances when we have reason to believe that a pedagogical choice may have arisen from feedback the teacher received.

Each teacher chose one section of 7<sup>th</sup>-grade science as the focal class for the study. Student racial/ethnic demographics in the focal classes (Table 3) approximated the school as a whole. There was no indication that Joanne or Steve chose classes with any special characteristics, although Joanne’s class had multiple students with learning needs and two adult teaching aides to support those students. Sandra chose her “STEM class,” a designation given to a section of students who had been nominated for that placement by other teachers. All students

in the three classes completed all research activities, but active parental consent and student assent were obtained for use of student data for research purposes.

**Table 3**

*Student Demographic Data for Focal Classrooms*

| School                          | School A |     |          |     | School B |     |
|---------------------------------|----------|-----|----------|-----|----------|-----|
| Teacher                         | Joanne   |     | Steve    |     | Sandra   |     |
| Focal class                     | 1st hour |     | 2nd hour |     | 5th hour |     |
| Class period length (min)       | 60       |     | 55       |     | 52       |     |
| Class size (total) <sup>a</sup> | 34       |     | 32       |     | 28       |     |
| Research sample                 | n=23     |     | n=21     |     | n=20     |     |
|                                 | n        | %   | n        | %   | n        | %   |
| Female                          | 15       | 65% | 11       | 52% | 9        | 45% |
| White                           | 14       | 61% | 14       | 67% | 1        | 5%  |
| Black                           | 3        | 13% | 4        | 19% | 19       | 95% |
| Latinx                          | 3        | 13% | 3        | 14% | 0        | 0%  |
| Asian                           | 0        | 0%  | 0        | 0%  | 0        | 0%  |
| Multi-racial                    | 1        | 4%  | 0        | 0%  | 0        | 0%  |
| American Indian                 | 2        | 9%  | 0        | 0%  | 0        | 0%  |
| English Language Learner        | 2        | 9%  | 0        | 0%  | 0        | 0%  |
| Special Education status        | 5        | 22% | 2        | 10% | 0        | 0%  |

<sup>a</sup>Total class size reflects the maximum number of students enrolled in the class at any point during implementation. All three classes experienced some fluctuation in student enrollment.

### Data and Measures

Data collection began in November (School B) and December (School A) 2019 and

ended in March 2020 when schools statewide closed due to the COVID-19 pandemic.

### ***Survey***

Approximately two weeks before the focal unit began, students completed a survey that measured multiple constructs related to their initial science motivation, including students' mastery, performance-approach, and performance-avoidance goals and their self-efficacy in science class. All measures included Likert scale items adapted from the Patterns of Adaptive Learning Scales (PALS; Midgley et al., 2000) with response options ranging from 1 (not at all true) to 5 (very true). Mastery goal orientation (e.g., "One of my goals in science is to learn as much as I can";  $\alpha = 0.78$ ,  $\omega = 0.79$ ), performance-approach goal orientation (e.g., "It's important to me that other students think I am good at science";  $\alpha = 0.85$ ,  $\omega = 0.87$ ), and self-efficacy (e.g., "I'm certain I can master the skills taught in science";  $\alpha = 0.87$ ,  $\omega = 0.87$ ) were each measured with four items, and performance-avoidance goal orientation (e.g., "It's important to me that I don't look stupid in science";  $\alpha = 0.79$ ,  $\omega = 0.79$ ) was measured with three items.

### ***Classroom Video***

Teachers used a video recording system that followed their movement around the classroom by tracking a marker (which also served as a microphone) that they wore on a lanyard. They filmed daily over a span of 10-13 weeks during the instructional unit, apart from occasional disruptions. Within each classroom, we collected students' reports of their classroom experience on approximately 12 of the videorecorded days through brief surveys called end-of-class reports (ECRs, described below), which produced a total of 35 videos that could be paired with contemporaneous student-report data. From these 35 videos, we selected five videos to analyze from each teacher, for a total of 15 videos in the final data corpus. Our selection criteria for the

videos were: 1) a video and ECR pairing of the same or similar<sup>2</sup> lesson activities existed for at least two but ideally all three teachers (i.e., videos were selected to represent “comparable” lessons); 2) the videos were from different time points during the unit; and 3) the videos represented a range of instructional activities (e.g., investigations, discussions, data analysis) and modalities (e.g., whole-class, group work, individual).

All videos in the data corpus were recorded during the unit “Introduction to Chemistry 2: How Can I Make New Stuff From Old Stuff? Chemical Reactions and Conservation of Matter” from the NGSS-aligned curriculum *Investigation and Questioning our World through Science and Technology* (IQWST; McNeill et al., 2009; Activate Learning, 2019). In the first lesson (Video 1: “Phenomenon”), students experienced an anchoring phenomenon by placing loosely crumpled aluminum foil in copper chloride solution, causing what they would later learn was a chemical reaction: the substances changed color and gave off heat as they transformed into copper metal and aluminum chloride. As students sought to understand this phenomenon in subsequent lessons, they engaged with disciplinary core ideas, crosscutting concepts, and science and engineering practices, such as intensive properties of substances (Video 2: “Substances”), including hardness (Video 3: “Hardness”) and density (Video 4: “Density”); molecular models; and identification and scientific explanation of chemical reactions such as acid rain and copper (Video 5: “Acid Rain”). All three teachers were teaching this unit for the first time, though Joanne and Steve had experience teaching other IQWST units, whereas Sandra did not.

### ***End-of-Class Report (ECR)***

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<sup>2</sup> IQWST is not a strictly scripted curriculum and encourages teacher flexibility and discretion in the enactment and pacing of its lessons to support student understanding. See online appendices for more detail about variation in lesson activities across the teachers.

At multiple points throughout the unit, students completed an end-of-class report (ECR) in which they responded to several survey items that used the question stem “How much did these things happen in class today?” to ask about the teacher’s support for motivation and engagement during the immediately preceding science lesson. Two items adapted from the PALS Perception of Teacher’s Mastery Goal scale (Midgley et al., 2000) were included on the ECR to measure students’ perception of teacher’s mastery goal support (TMS; Spearman-Brown reliability = 0.73) in the lesson: [1] *My teacher wanted me to really understand what we were doing, not just memorize it;* and [2] *My teacher made it clear that mistakes are OK as long as we are learning.* All ECR items were Likert-type items with response options ranging from 0 (not at all) to 3 (very much). In methodologies designed to collect repeated measures, short scales are generally preferable to longer, multi-item scales (Csikszentmihalyi & Larson, 2014; Goetz et al., 2016; Hektner et al., 2007; Zirkel et al., 2015). While the TMS scale, especially in its shortened form on the ECR, does not cover all aspects of the TARGET+3 framework, it has been used in prior studies as a measure of mastery goal structure of classrooms (e.g., Ryan et al., 1998; Urdan & Midgley, 2003) and reflects the ultimate goal of a mastery goal structure, which is students’ perception that the teacher’s instruction communicates an emphasis on developing, rather than performing, competence. The online appendices include additional details about our procedures for validating the short scale.

Students in Joanne’s and Steve’s classes completed 12 ECRs and Sandra’s students completed 11.<sup>3</sup> We analyzed only those ECRs corresponding to the focal lessons. Across the five lessons, students’ average ECR completion was 4.4, 4.6, and 4.5 in Joanne’s, Steve’s, and Sandra’s classrooms, respectively. Missing ECR data was almost entirely attributable to student

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<sup>3</sup> The 12<sup>th</sup> ECR in Sandra’s class was canceled when schools closed due to COVID-19.

absences, which averaged about two per lesson in each classroom.

### **Analytic Approach**

In order to avoid biasing either analytic strand, we performed the qualitative and quantitative analyses separately. The first and third authors, along with a graduate research assistant, coded the classroom videos to develop case narratives. The second author led the quantitative analysis.

### ***Qualitative Analyses***

From the classroom videos, coders produced running records (Patrick et al., 1997) and timelines of instructional events (Erickson, 2006). Coders developed consistency in these procedures on three of the 15 videos (20% of the data corpus). They then analyzed each video using a template for protocol coding (Miles et al., 2019) with prompts to guide the coder's selection of evidence from the lesson (time-stamped text from the running records) related to each of the TARGET+3 categories from the Observing Patterns of Adaptive Learning (OPAL) protocol (Patrick et al., 1997; Table 1). Coders normed the coding template on two videos. The format of the coding template did not support the calculation of an agreement statistic, but it provided a consistent structure in which to juxtapose each coder's evidence within each category and assess agreement and discrepancies so that the higher-level patterns identified in the next round of analysis were based on a common foundational understanding. As prior work has noted overlap or clustering of the TARGET+3 categories (e.g., Patrick et al., 2001), the template also accommodated the inclusion of evidence in multiple categories (i.e., double-coding) to support more complex interpretations of the classroom goal structure. For example, the participation structure is considered a Task feature but also provides insight into the Social and Authority dynamics of a given classroom.



The first author coded all 15 videos, and nine videos were coded a second time (three out of the five videos in each teacher's corpus or 60% of the video data; see online appendices). After coding each video, the coders further condensed the data by populating a series of matrices (Miles et al., 2019) with key themes from the observed evidence to facilitate the identification of patterns within and across teachers, TARGET+3 categories, and lessons. Coders met periodically to reconcile differences in the coding templates and the thematic matrices. From the matrices, the coders compiled key findings for each teacher that were supported by evidence from multiple videos and accompanied by counter-examples where available to ensure the consideration of alternative hypotheses (Maxwell, 2010). They then further prioritized findings that were replicated or contrasted in the other teachers' data, in keeping with a multiple-case study approach (Yin, 2009).

### ***Quantitative Analyses***

The second author conducted the quantitative analyses concurrently but separately from the qualitative analyses. All statistical analyses were conducted using the R statistical software (RStudio Team, 2020) using the *psych* (Revelle, 2020), *lavaan* (Rosseel, 2012), and *multcomp* (Hothorn et al., 2008) packages.

**Initial Achievement Goal Orientations and Self-Efficacy.** Differences in class means for each construct were assessed using a one-way analysis of variance (ANOVA). For constructs with significant differences between classrooms, as indicated by a significant F-test, post-hoc Tukey all-pairwise comparisons were performed. Five students (8%) in the sample did not complete the survey and thus did not have scale scores for these measures.

**Perceptions of Teacher Mastery Goal Support.** We calculated a mean of the two ECR items measuring perceptions of teacher mastery goal support for each student. Mean scores were

not calculated for seven students (1% of ECR observations) who only responded to one of the two items for a given lesson. We also calculated class means and standard deviations of student perception of mastery support for each lesson and across the five lessons.

### ***Integrated Analysis***

We integrated our analyses at the individual case level as well as across cases. We refined our key themes for each teacher to prioritize the themes that were most relevant for interpreting that teacher's quantitative data, as well as themes that facilitated cross-case comparison (Figure 1). This refined list of themes informed the composition of each case narrative, the content and design of the final tables and figures, and the sequencing of the narratives and quantitative results within this manuscript to present a cohesive data story. Table 4 summarizes the key qualitative themes for each teacher that are elaborated in the case narratives, as well as practices that overlapped across the three teachers and therefore are not discussed at length in the cases.

### **Researcher Positionalities**

Our use of mixed methods in this study stemmed from a stance of pragmatism, which acknowledges the value of drawing from varied epistemological and methodological frameworks. Among these is a commitment to transparency and self-reflexivity as key components of qualitative methods (Luttrell, 2000; Willig, 2013) that are also relevant for quantitative analyses (Garcia et al., 2018). Thus, before presenting our results, we share information about our researcher identities and how we positioned ourselves in relation to our participants and research questions that readers may find salient for interpreting and evaluating our findings.

The first author identifies as second-generation Asian American while the other co-authors identify as non-Hispanic White. We are all highly educated and consider ourselves

middle- or upper-middle class. These identities shape the way we experienced education and the way we interpret instructional interactions. Of particular note for this study, we may view classroom practices differently than the students we surveyed, which is an important lens for considering the integrated phase of analysis when we merge our qualitative observations with the quantitative student-report data.

The three authors who were most directly involved in data analysis were all teachers in public K-12 schools before becoming researchers, which informs our perspective on classroom practices and interactions. The first and third authors, who performed the qualitative analysis, were English teachers; the second author, who led the quantitative strand, was a science teacher whose critical perspective on the qualitative analysis was especially welcomed at the integrative phase. The third author was also the only author who had no relationship with the participants prior to data analysis, making her perspective on the videos an important counterpoint to mitigate potential bias in the first author's interpretations. However, despite the salience of teaching in our professional self-identifications, our participants probably viewed us primarily as researchers or teacher developers. Five of the co-authors had delivered parts of the professional learning (PL) institute on motivationally supportive teaching practices that the participants had attended prior to data collection, and the first author was involved in giving the teachers feedback using some of the videos and ECRs included in the present study's data corpus.

We view our teacher-scholar identities and careful consideration of participant relationships as assets and feel our transparency about these tensions enhances our work (Fine & Weis, 2010). As part of our ongoing relationship-building efforts, we shared this manuscript with the teachers prior to submitting it for peer review in order to solicit their responses and resolve any concerns they might have about their depiction. We believe that achieving a more nuanced

empirical understanding of how teachers enact goal structures in their classrooms requires that we afford teachers the opportunity to further explain or contextualize their teaching practices and carefully consider how we represent teachers and their classrooms in scholarly journals. We hope that doing so helped to move us closer to the productively “uncomfortable reflexivity” (Pillow, 2003) that is necessary for researchers to confront the direct implications of their work for the participants themselves, not just an abstract knowledge base (Liu, 2020). Each teacher affirmed that their case narrative was fair in its depiction of their classroom and that the findings were resonant and prompted them to reflect on their practice. No one requested any changes, but we made a few minor revisions in light of the responses.

**Table 4**

*Summary of Key Findings from Qualitative Coding by Focal Teacher*

| Category | Joanne                                                                                                             | Steve                                                                                                 | Sandra                                                         |
|----------|--------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|
| Task     | <i>Little variety in tasks or differentiation within classrooms: students worked on the same tasks<sup>a</sup></i> |                                                                                                       |                                                                |
|          | <i>Limited rationale provided for tasks<sup>a</sup></i>                                                            |                                                                                                       |                                                                |
|          | Many types of activities                                                                                           | <i>Frequent teacher-centered instruction</i>                                                          | <i>Fragmented feeling to class activities</i>                  |
|          | Egalitarian participation structures                                                                               | Teacher follows up for accuracy, accountability, and challenge; but uses <i>punitive cold-calling</i> | <i>Relies primarily on volunteers for participation</i>        |
|          | <i>Limited challenge</i>                                                                                           |                                                                                                       | Teacher developing discourse strategies to press for reasoning |
|          | <i>Teacher takes main responsibility for learning</i>                                                              | Culture of question-asking and curiosity                                                              |                                                                |
|          | Positive teacher and student affect about social interaction but <i>not academic content</i>                       | Positive affect from teacher and some students toward science                                         | Strong support for question-asking                             |

|                        |                                                                                                                                            |                                                                                                                                                                                                     |                                                                                                                                                                                       |
|------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Authority/<br>Autonomy | Autonomy-supportive classroom management<br><br><i>Weaker supports for cognitive autonomy due to limited academic challenge</i>            | <i>Authoritarian management style emphasizing teacher control over student autonomy</i><br><br>Question-asking culture supports cognitive autonomy for some, <i>but possibly not all</i> , students | Autonomy-supportive classroom management with <i>some controlling practices</i><br><br><i>Mixed support for cognitive autonomy</i>                                                    |
| Recognition            | Neutral recognition encourages participation over competition                                                                              | <i>Recognition may highlight social comparison by casting students into roles</i>                                                                                                                   | <i>Inconsistent recognition patterns may focus students on correct answers</i>                                                                                                        |
| Grouping               | Students seated in groups assigned by teacher; unknown rationale for seat assignments but no evidence of ability grouping <sup>a</sup>     |                                                                                                                                                                                                     |                                                                                                                                                                                       |
| Evaluation             | Little emphasis on formal evaluation                                                                                                       | <i>Leveraged threat of evaluation for compliance</i>                                                                                                                                                | Mixed – few mentions of evaluation, but <i>used for compliance when mentioned</i>                                                                                                     |
| Time                   | Little sense of teachers rushing students to work quickly <sup>a</sup>                                                                     |                                                                                                                                                                                                     |                                                                                                                                                                                       |
|                        | Classroom timer to guide students, but flexible timing for tasks                                                                           | Rarely mentions time or timing estimates                                                                                                                                                            | Flexible timing but <i>frequent language about “moving on” and one competitive task rewarding speed</i>                                                                               |
| Social                 | Warm, positive social climate<br><br>Teacher self-disclosure and personal knowledge of students<br><br>Noncompetitive student interactions | <i>Climate of boundary testing and possibly combative bantering</i><br><br>Teacher self-disclosure and personal knowledge of students<br><br>Rapport-building through discussing science            | Warm, mutually respectful climate<br><br>Affectionate language and warm demeanor from teacher but <i>little evidence of overt relationship-building or student perspective-taking</i> |

|                  |                                                                                                                                                       |
|------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| General Messages | Occasional positive messaging about science but <i>few adaptive messages about coping with challenge or value of effort<sup>a</sup></i>               |
|                  | <i>May make performance salient by using “smart/stupid” language</i>                                                                                  |
| Help             | Teachers circulate frequently and provide help when near students; few clear patterns about help-seeking behaviors or norms/expectations <sup>a</sup> |

*Note.* Practices that align with mastery goal structure as articulated by extant theory and research are in plain text. Practices that potentially undermine mastery goals and/or promote performance goals are italicized.

<sup>a</sup> Findings are not discussed in case narratives due to lack of variation between teachers.

## Results

### Initial Student Motivation in Focal Classes

To provide some context for the instructional and interactional dynamics featured in the qualitative case narratives, we first describe patterns observed across the three classes with respect to students' initial achievement goal orientations and self-efficacy, measured approximately two weeks before the focal unit began. Students' mastery goals were, on average, above the mid-point of the scale, while class-level means for performance goals were considerably lower, especially performance-approach goals (Table 5). The three classes did not significantly vary in terms of initial levels of students' personal goal orientations (mastery, performance-approach, performance-avoidance). On average, Sandra's students reported the highest levels of mastery goals, followed by Joanne's and then Steve's students. Performance-avoidance goals were also highest among Sandra's students, followed by Steve's and then Joanne's students. Steve's students reported the highest levels of performance approach goals, followed by Sandra's and then Joanne's students.

There were, however, significant differences in initial self-efficacy by class (Table 5). Post-hoc Tukey's all-pairwise comparisons indicated that students in Steve's class had significantly lower self-efficacy than students in Sandra's class, while students in Joanne's class were in the middle and did not significantly differ from students in Steve's or Sandra's classes.

**Table 5**

*Means and Standard Deviations (in Parentheses) of Scale Means for Student Goal Orientation and Self-Efficacy by Focal Class*

|                             | Joanne<br>(n=23) | Steve<br>(n=21)          | Sandra<br>(n=20)         |                             |
|-----------------------------|------------------|--------------------------|--------------------------|-----------------------------|
| Mastery goals               | 3.26 (0.83)      | 3.05 (1.07)              | 3.58 (0.86)              | $F_{2, 56}=1.56, p = 0.217$ |
| Performance-approach goals  | 1.52 (0.78)      | 1.91 (1.08)              | 1.89 (1.10)              | $F_{2, 56}=0.98, p = 0.381$ |
| Performance-avoidance goals | 2.17 (1.25)      | 2.60 (1.27)              | 2.81 (1.27)              | $F_{2, 56}=1.31, p = 0.278$ |
| Self-efficacy               | 3.61 (0.81)      | 3.01 (1.02) <sup>a</sup> | 4.03 (0.98) <sup>a</sup> | $F_{2, 56}=5.65, p = 0.006$ |

<sup>a</sup> Mean self-efficacy significantly differed between Steve's and Sandra's classes,  $p = 0.004$

### Overview of Case Narratives and Quantitative Case Results

Below, we present a detailed case narrative about each teacher, developed from our qualitative coding of the five videos (V1-5), the quantitative student-report data for the same five lessons, and an integrated discussion of key takeaways. The cases take an integrative approach to the TARGET+3 categories (which appear as bolded keywords), first highlighting the teacher's areas of strength in supporting mastery goals and then discussing practices theorized to undermine mastery goals or promote performance goals. We emphasize that these case studies are not evaluations of the participants as "good" or "bad" teachers, or even as strong or weak in

mastery goal structure implementation. As such, we minimize comparisons between teachers within the case narratives to allow readers to focus on the unique goal structure configuration within each classroom.

Following each case narrative, we present quantitative case results in which we describe variation in student perceptions of the case teacher's mastery goal support within and between lessons, then integrate these observations with the case narratives by noting consistencies and inconsistencies between the qualitative and quantitative data sources. Because students' reasons for responding as they did on the ECRs are unknown, these integrated interpretations are not meant to claim causal links but rather to propose plausible associations between the observed goal structure and students' perceptions.

#### **Case Narrative #1: Joanne**

Joanne had taught at School A (64% FRPL; 59% non-Hispanic White) for 20 years and had 25 years of total teaching experience. She held a bachelor's degree in elementary education and a master's in K-8 science education. Her focal class for data collection was her first hour class with 34 students. Five students in the research sample (n=23) had special education status requiring the presence of two teaching aides for inclusion support.

#### ***Positive Social Climate and Autonomy Support***

Joanne's strongest supports for mastery tended to relate to the **social** dynamics of learning. Her classroom climate was consistently warm and supportive. It was evident that Joanne held a lot of knowledge about her students as individuals, some of which she obtained through classroom routines such as the "Monday morning share," in which she spent the first few minutes of Monday's class every week inviting students to share with the class something they had done over the weekend. When this routine occurred, many students raised their hands



immediately, and Joanne seemed to try to call on everyone who wanted to speak. Joanne also took advantage of spontaneous moments to either glean or use personal knowledge about specific students or to otherwise connect with them over their interests.

In return, Joanne also disclosed personal information about herself to her students. Through asides and comments in multiple videos, it was apparent that the students were familiar with her family, including her adult children. When discussing concerns about COVID-19 at the beginning of the acid rain lesson (V5), Joanne told the class about her own concerns about her elderly father. In all five videos, she frequently circulated throughout the classroom and had numerous casual exchanges in which both she and the students referred to shared knowledge about each other.

Joanne's classroom management strategies were **autonomy**-supportive and often preemptive, anticipating students' needs to avoid future management issues. A prominent example of this was the two-minute break that Joanne gave the students in nearly every lesson, where she would set the classroom timer and allow students to get out of their seats and talk with friends. Students would then automatically return to their seats when the timer rang, often without Joanne saying anything. When necessary, Joanne used autonomy-supportive routines to recapture the class's attention, such as counting down from three or holding up a hand, instead of more controlling techniques such as calling out individual students. When confronting student frustration or other management issues, Joanne tended to do so privately, and on two occasions either allowed or offered a student the option of leaving the classroom to "take a walk" in the hall and cool down. In the hardness lesson (V3), she expressed disappointment at how students had conducted themselves the last time they were allowed to choose groups but addressed this in an autonomy-supportive way by asking the students to generate ideas for additional lab

expectations before once again allowing them to choose their groups.

Joanne also supported **autonomy** by acknowledging students' perspectives during academic tasks. For example, in the density lesson (V4), Joanne planned for the students to use small white boards for a group activity but acknowledged, "I know you all want to draw on them before you have to do the work on them" and facilitated a collaborative drawing game before asking the students to use the white boards for the intended academic purpose. Joanne also consistently said "please" and "thank you" to students, which modeled prosocial behavior and reflected an understanding of students as autonomous beings who deserve respectful treatment. She encouraged similarly prosocial behavior among the students by thanking or praising students who helped each other.

### ***Downplayed Competition and Formal Evaluation***

Many of the ways in which Joanne structured **tasks** in her class both contributed to and leveraged the warm and autonomy-supportive social climate. Joanne incorporated many different activities and varied instructional modalities into the IQWST curriculum, which created opportunities for students to collaborate and learn from each other in different ways. For example, the white board activity in the density lesson (V4) was to draw a representation of a "riddle" derived from a question in one of the texts: "What's the difference between a pound of feathers and a pound of bricks?" Joanne also employed collaborative and active reading strategies in two lessons: a jigsaw protocol for the density reading in V4 and group summaries of the acid rain reading in V5.

In many of these **tasks**, Joanne provided guidance to students about how to collaborate effectively, such as in the acid rain reading summary activity in V5 when she suggested that groups decide on a scribe and a spokesperson but make sure that everyone "comes to consensus."

Her tasks often featured egalitarian participation structures. She used frequent turn-and-talk strategies and varied her method of calling on students so that volunteers did not dominate. On one occasion she used strips of paper with students' names on them to randomize who she called on, but only after allowing students to discuss the prompt in groups, making this technique a "warm call" as opposed to a cold call.

Consistent with the egalitarian participation structure and supportive social climate, Joanne's approach to **evaluation** and **time** seemed to downplay competition. She rarely mentioned formal evaluation or grades. Although she frequently used the classroom timer and announced the duration of each task as part of the instructions, she was flexible with time estimates and often extended time if she deemed it necessary, including explicitly pointing out the extended time to students in two lessons. Our general sense was that time estimates were provided for clarity and structure rather than pressure to work faster. Possibly as a result of these teaching strategies, Joanne's students interacted with each other in tolerant and largely noncompetitive ways, and they were also notably compliant in engaging with the assigned tasks. There was little evidence of conflict between students, disengagement, or off-task behavior, and the class as a whole was accepting of their peers with learning needs.

### ***Consistency, with One Exception***

These features of Joanne's classroom goal structure were remarkably consistent: her class "felt" the same in every video with the notable exception of the hardness lesson (V3). On this day, both of Joanne's usual classroom aides were absent, and the lesson featured the most prominent examples of conflict between students as well as between Joanne and individual students; it supplied many of the exceptions in our thematic analysis of the **social** and **authority** codes. For example, when students chose their groups for the hardness investigation, one of the

students with special needs could not seem to find a lab group, though it was unclear from the video to what extent classmates were actively excluding him versus simply making no effort to invite him in.

Later, as the class worked individually on Claim-Evidence-Reasoning (C-E-R) paragraphs, Joanne herself got into an extended conflict with another student, Eddie,<sup>4</sup> which escalated to the point where Joanne took his binder and placed it on a solo desk at the side of the room to try to force him to change seats, which he refused to do. Shortly afterwards, Eddie played a central role in some fraught peer dynamics and a more frustrated response from Joanne than was typical:

Eddie, angrily: “I don’t know how to do it!” Student B: “You don’t know how to write?”

Joanne reaches out to Student B and starts to say, “This is none of your business to get into” as Eddie says, “Can you shut up?!” Someone says, “You said it first!” Joanne turns around and fixes her eyes on Student C: “Is it any of your business to get into?” She stands holding his eye contact while pointing behind her back at Student B for several seconds, then walks away...a few moments later, Eddie’s hand goes up and he calls out to Joanne, who responds, “Yes, darling?” Eddie is inaudible, perhaps saying again that he won’t move his seat. Joanne: “You already told me that. I’m not going to force you.” Eddie: “I don’t know how to do this. I wasn’t paying attention.” Joanne: “OK, well when you’re ready to talk to me respectfully, I will happily—” Eddie interrupts her, inaudible. Joanne: “No, honey. You have a really not-nice tone today.” Eddie tips his

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<sup>4</sup> All student names are pseudonyms. We use pseudonyms only when necessary for narrative clarity or when students feature prominently in multiple classroom exchanges that seem relevant to our case interpretation of students’ perceptions of mastery support.

head back and groans. Joanne, in a dramatic voice: “I *know*, that’s how I feel today also.” Eddie: “Can you please help me?” Joanne explains that he’s answering a question and reads it aloud to him: “Does the size of a substance affect its properties?” Eddie: “No.” Joanne: “So you say, ‘No, the size does not affect its properties.’ Start there.” Eddie starts writing.

However, even in this moment, Joanne still demonstrated some of her usual patterns of warmth and support for autonomy, such as continuing to be responsive to Eddie despite their mutual frustration. These practices may have contributed to Eddie eventually taking some responsibility by admitting, “I wasn’t paying attention,” and calming down sufficiently to ask for help politely.

### ***Limited Challenge and Press***

Eddie was not the only student who struggled with the C-E-R in V3; the captured audio of Joanne’s individual consultations revealed that many students experienced difficulty. We speculated that writing a C-E-R may have presented an unusual level of challenge for Joanne’s students relative to more typical **tasks** in the five lessons. Joanne seemed to achieve her egalitarian participation patterns in part by providing safe access points for students using low-level prompts. For example, in the substances lesson (V2), Joanne distributed a vocabulary sheet with definitions and a periodic table and invited students to share what they “noticed” on the sheet, which prompted many volunteers but little substantive conversation about the terms; the definitions themselves were ultimately read aloud by either Joanne or a student volunteer with little active engagement around them. In the acid rain lesson (V5), after checking the students’ homework, Joanne observed that they seemed “confused” about chemical reactions, but she did not ask any students for their reasoning when they shared their ideas, which could have helped to identify and address their misconceptions.

Joanne's frequent use of neutral, non-evaluative **recognition** patterns, such as repeating a student's response verbatim, seemed to support the social dynamics in the class by encouraging more students to participate but did not always provide opportunities for academic press or follow-up questioning to probe students' thinking more deeply. For example, when she used the name strips to ask students what soap or fat were used for, she repeated each student's response without judgment and pivoted to the next student, even when students repeated responses that had already been said. This likely promoted the willingness of students to speak when called upon, but the task never evolved into a more challenging one, and Joanne moved on to a new activity after hearing from several students.

Because the students were rarely asked to share their reasoning or contribute higher-order thinking in public classroom discourse, Joanne was most often positioned as the scientific **authority** in the focal videos: she was primarily responsible for the more challenging cognitive work in the classroom. Though Joanne used autonomy-supportive classroom management strategies, her students did not experience much cognitive **autonomy** or opportunities to direct their own learning. For example, Joanne told the class in the phenomenon lesson (V1) that they would be "going backwards just a little bit" and executing the procedures step by step together "just for practice sake" since "this is our first lab we've done in a while." This level of scaffolding seemed unnecessary and removed responsibility from students for following the lab procedures.

When combined with the previously noted **timing** patterns, these **task** and **recognition** features contributed to conveying a lack of urgency in Joanne's class that potentially undermined a focus on mastery and learning. Although flexible timing is generally considered mastery supportive, the limited challenge in Joanne's tasks contributed to a feeling of little momentum

building toward scientific understanding. In two of Joanne's lessons (V1, V4), the main academic task did not begin until approximately 25 minutes into the 60-minute period. In the density lesson (V4), the white board drawing game took nearly 10 minutes whereas the academic task of representing the feather/bricks riddle received less than 4 minutes and the representations were not discussed, nor retained for future discussion.

### ***Compliance, but Little Curiosity***

The teacher and student affect we observed during academic **tasks** in Joanne's videos did not always seem aligned with a mastery approach to science learning. While Joanne consistently appeared enthusiastic about interacting with students and sometimes expressed enthusiasm about science in general, such as telling students, "You're going to be mad, mad scientists today!" this explicitly pro-science messaging and enthusiasm rarely extended to specific tasks or concepts. The one exception was in the phenomenon lesson (V1) when Joanne played along with the students' surprise at the reaction between aluminum foil and copper chloride; at one table, she exclaimed, "Woah! What's coming off of there?" Similarly, while Joanne's students were notably compliant during academic **tasks**, there was little evidence of students' overt interest or enthusiasm, especially compared to their eagerness during social activities like the Monday morning share or the drawing game. Joanne's video corpus was unique among the three teachers in that we did not identify a single example of students asking her spontaneous questions related to the focal science content, apart from their reactions to the phenomenon in V1 that were largely rhetorical questions (e.g., "Is that rust?").

### ***Summary***

Overall, many features of Joanne's classroom goal structure seemed to encourage inclusive and equitable participation and positive social dynamics that have been shown in prior

research to promote student perceptions of mastery support. These trends were fairly consistent across the five lessons. However, Joanne rarely leveraged those positive social dynamics for deeper science learning. This may be why her students seemed to struggle in the relatively rare instances when they encountered more difficult tasks that required them to demonstrate their scientific understanding. Joanne seemed to have created a safe and supportive classroom climate for students to take on challenging work, but she did not necessarily take advantage of that strong foundation to press students for their sense-making and reasoning on a regular basis.

### **Student Perceptions of Joanne's Mastery Support**

#### ***Overall Teacher Mastery Support Perceptions***

Joanne's students, on average, reported teacher mastery support above the mid-point of the 0-3 Likert scale in all five lessons (Table 6). Consistent with our qualitative observation that Joanne's class "felt" the same most days, students' mean perceptions of mastery support did not vary much from day to day, with the exception of the hardness lesson (V3), discussed further below. Standard deviations for perceived mastery support were consistently the lowest in this classroom among the three, indicating that Joanne's students generally seemed to be in agreement. The plot of individual student responses (Figure 2) revealed the same trend, with students typically forming one large cluster at or above the mid-point of the scale, with one or two outliers. The exception, again, was the hardness lesson (V3), where students were more varied in their responses.

#### ***Teacher Mastery Support Perceptions by Initial Mastery Goals***

Because prior work suggests that students' personal goal orientations may influence their perception of classroom goal structures (Senko et al., 2012), we examined the distribution of perceived teacher mastery support across students' initial goal orientations as well as self-



efficacy as measured on the student survey. Figures 3-6 display these data for each teacher and lesson. Students' survey means on the three initial goal orientations (Figures 3-5) and self-efficacy (Figure 6) are plotted on the x-axis (range 1-5), with their perceptions of teacher mastery support from the ECR on the y-axis (range 0-3). The dotted lines designate the boundaries for our interpretation of low ( $\leq 0.5$ ), moderate (between 0.5 and 2.5), and high ( $\geq 2.5$ ) levels on each scale, using ranges suggested by Wormington and Linnenbrink-Garcia (2017). To aid in the visualization of variation in perceived teacher mastery support across different levels of initial goal orientation and self-efficacy, data points are color-coded as low (purple), moderate (blue), or high (green) on the initial goal orientation and self-efficacy measures. Because of the difficulty of interpreting a single data point, we do not discuss results when only one student had a scale mean in a given range.

Figure 3 shows that Joanne's students with moderate initial mastery goal orientation (represented with blue dots) perceived fairly high teacher mastery support across the five lessons, with relatively little variation. None of these students ever reported teacher mastery support in the low range. However, perceived mastery support was more mixed among Joanne's students with higher initial mastery goal orientation (represented with green dots). These students were consistently the ones giving Joanne the lowest ratings of perceived mastery support in every lesson, and proportionately fewer of them reported high levels of perceived mastery support.

### ***Teacher Mastery Support Perceptions by Initial Performance Goals***

Most of Joanne's students were low in initial performance-approach goal orientation, and their perceptions of teacher mastery support varied quite a bit (Figure 4). Students with low initial performance-avoidance goal orientation likewise varied in their perceptions of teacher mastery support (Figure 5).

Only three students had moderate or high initial performance-approach goal orientation, and they tended to perceive relatively high teacher mastery support (Figure 4). More students held moderate initial performance-avoidance goal orientations, and they similarly seemed to perceive fairly high teacher mastery support relative to the low and high initial performance-avoidance groups. This pattern was particularly visible in the substances (V2) and density (V4) lessons. There were only two students with high initial performance-avoidance goal orientation, making interpretation difficult, but they tended to perceive moderate teacher mastery support, with the exception of the acid rain lesson (V5), where they both perceived quite high teacher mastery support.

### ***Teacher Mastery Support Perceptions by Initial Self-Efficacy***

Similar to the pattern seen with initial mastery goal orientation, a larger proportion of students with moderate self-efficacy reported the highest teacher mastery support across most lessons compared to students with high self-efficacy (Figure 6). The hardness lesson (V3) again showed somewhat more variation. Students with higher self-efficacy were generally more moderate and less varied in their perceptions of teacher mastery support compared to students with moderate self-efficacy, with the exception of the substances lesson (V2), where both groups seemed to report a similar range of moderate-to-high levels of teacher mastery support.

### ***Key Findings and Variation by Lesson***

Consistent with our observations about it being an exception among Joanne's lessons, the hardness lesson (V3) had the lowest class-level mean perceived teacher mastery support and largest standard deviation (Table 6); additionally, student perceptions of teacher mastery support for this lesson were more evenly distributed across the full range of possible results compared to any other lesson (Figure 2). The students reporting the lowest perceived mastery support in V3

tended to be the ones with moderate or high initial mastery goal orientation (Figure 3) and self-efficacy (Figure 6), as well as low initial levels of both performance goals (Figures 4 and 5). It seemed that V3 felt as “off” in teacher mastery support to Joanne’s students as it had to us while coding the video. However, given that we found aberrations in this lesson in terms of both social dynamics (e.g., the peer conflict and Joanne trying to force Eddie to move) and academic challenge (the C-E-R task), it was difficult to pinpoint what the students may have been responding to in rating Joanne’s mastery support lower.

### ***Case Integration***

Joanne’s students, on average, rated her as providing relatively high levels of mastery support with the exception of the hardness lesson (V3), which was consistent with our qualitative analysis. Examining the data across initial goal orientations and self-efficacy, however, revealed possible nuances in the class-level story that could align with our qualitative conclusion that Joanne fostered an egalitarian and socially supportive environment with limited academic challenge. Students with moderate initial mastery goal orientation and self-efficacy perceived high levels of mastery support from Joanne, but students with higher initial mastery goal orientation and, to a lesser degree, self-efficacy did not necessarily perceive such strong teacher mastery support. An area of development for Joanne could therefore be working to strengthen the mastery goal structure of her classroom for the students who are already highly driven by mastery goals and feel very confident in science.

### **Table 6**

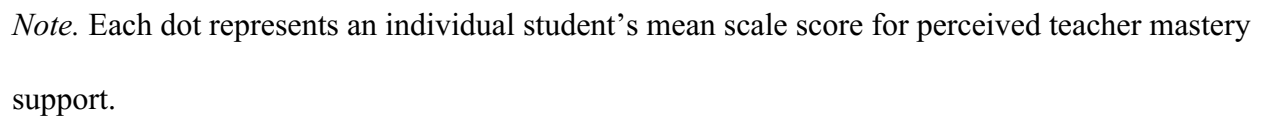
*Means and Standard Deviations (in Parentheses) of Teacher Mastery Support Scale (0-3) from End-of-Class-Reports for Each Teacher, Overall and by Focal Lesson*

|                 | Joanne<br>(n=23) | Steve<br>(n=21) | Sandra<br>(n=20) |
|-----------------|------------------|-----------------|------------------|
| Overall         | 2.04 (0.70)      | 1.12 (1.05)     | 2.19 (0.84)      |
| Phenomenon (V1) | 2.18 (0.65)      | 1.22 (0.86)     | 2.24 (0.66)      |
| Substances (V2) | 2.00 (0.63)      | 0.82 (1.00)     | 2.11 (0.85)      |
| Hardness (V3)   | 1.73 (0.85)      | 1.12 (1.02)     | 2.00 (0.97)      |
| Density (V4)    | 2.07 (0.64)      | 1.05 (1.24)     | 2.18 (0.87)      |
| Acid Rain (V5)  | 2.24 (0.68)      | 1.41 (1.09)     | 2.44 (0.85)      |

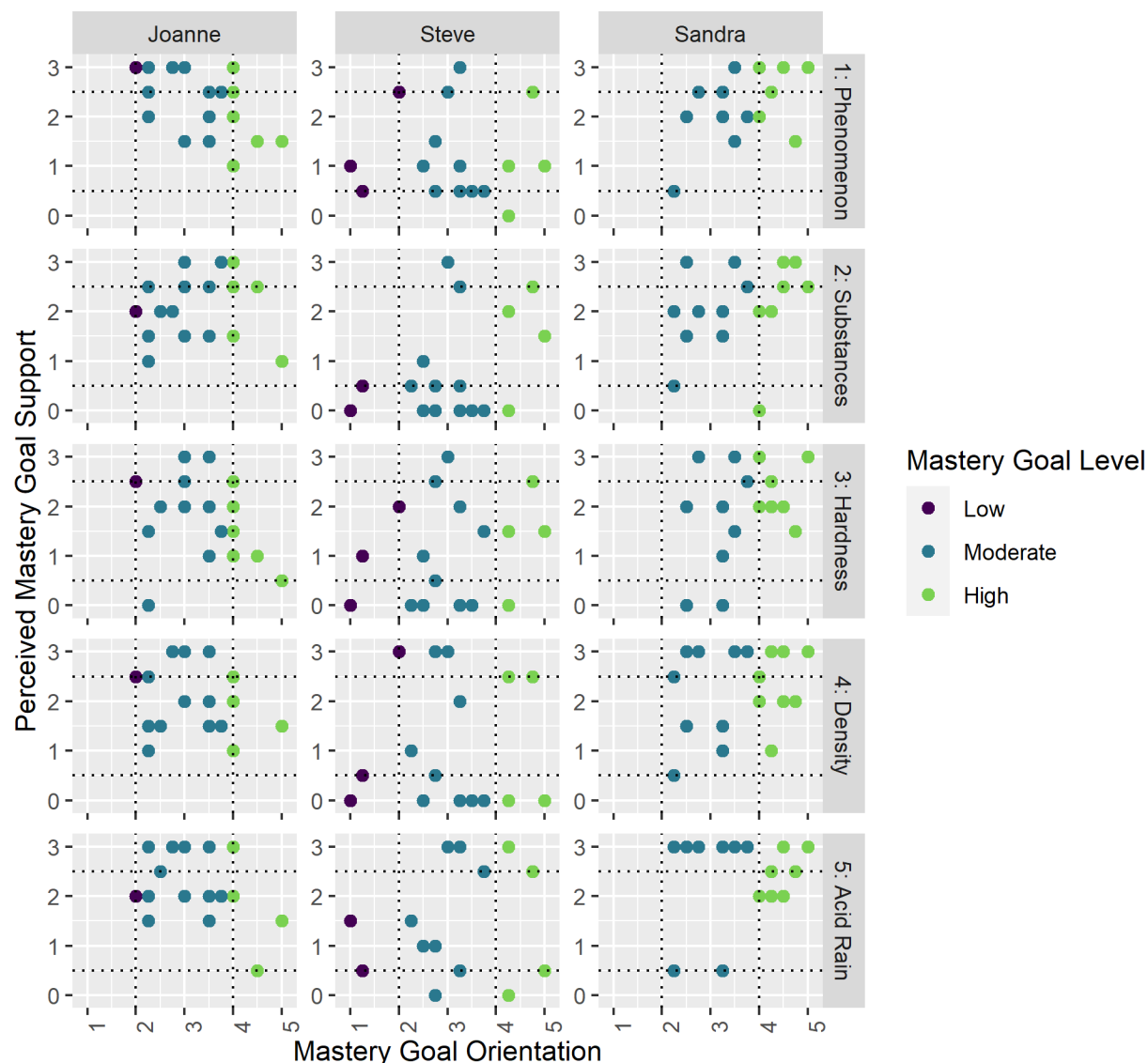
*Note.* For each ECR item, 0 = not at all, 3 = very much. The *n* for each class reflects the overall research sample. The sample for each lesson within a class varied due to student absences and enrollment changes.

## Figure 2

*Distributions of Students' Mean Perceived Teacher Mastery Support for Each Teacher by Focal Lesson*



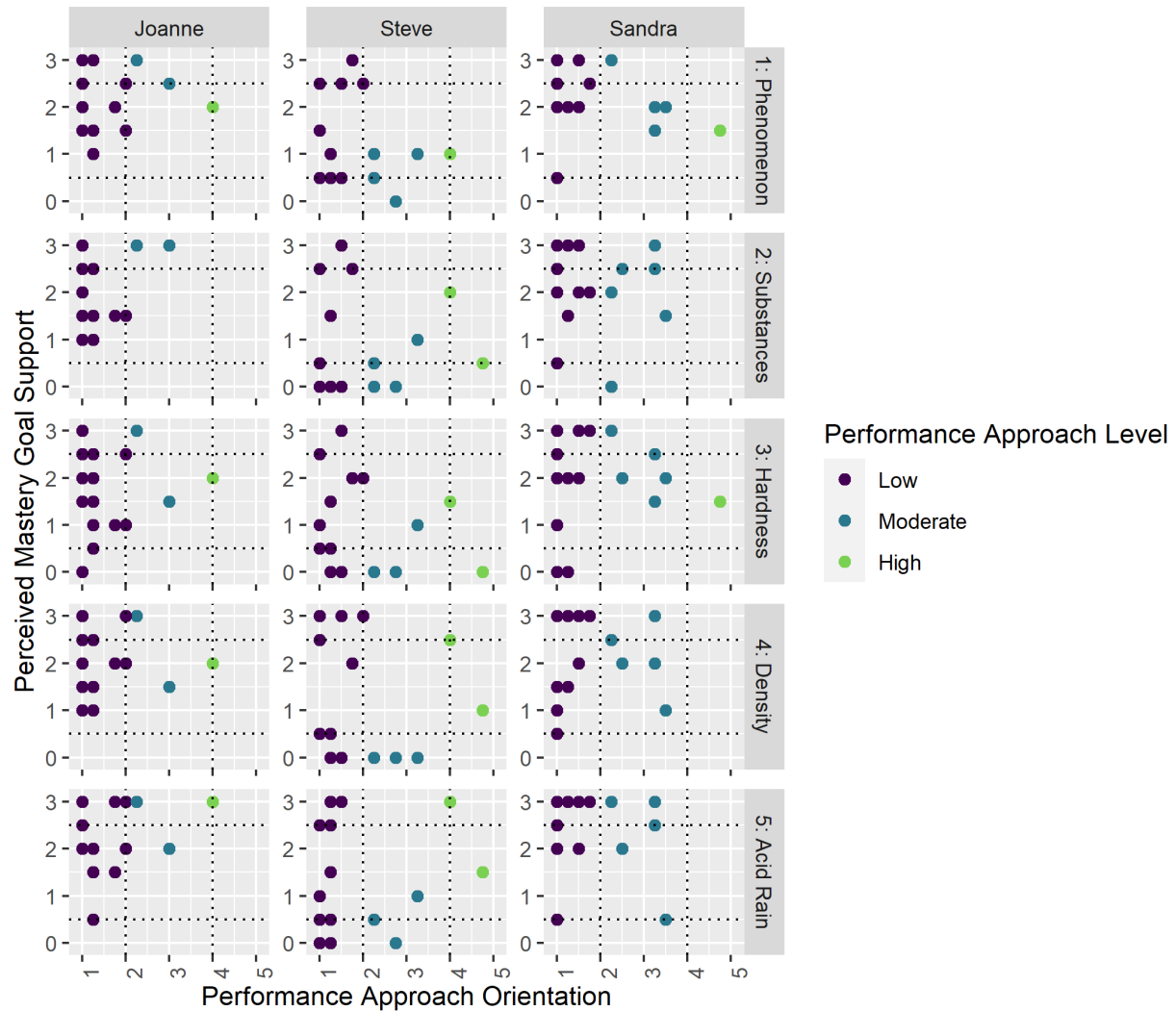
*Students' Mean Perceived Teacher Mastery Support by Mean Personal Mastery Goal Orientation, by Teacher and Focal Lesson*



*Note.* Each dot represents an individual student. Personal mastery goal orientation was an initial measure prior to the focal lessons. Lines designate our boundaries for low, moderate, and high levels on each scale. For personal mastery goal orientation: low  $\leq 2$ , moderate = between 2 and 4, high  $\geq 4$ . For perceived teacher mastery support: low  $\leq 0.5$ , moderate = between 0.6 and 2.4, high  $\geq 2.5$ .

**Figure 4**

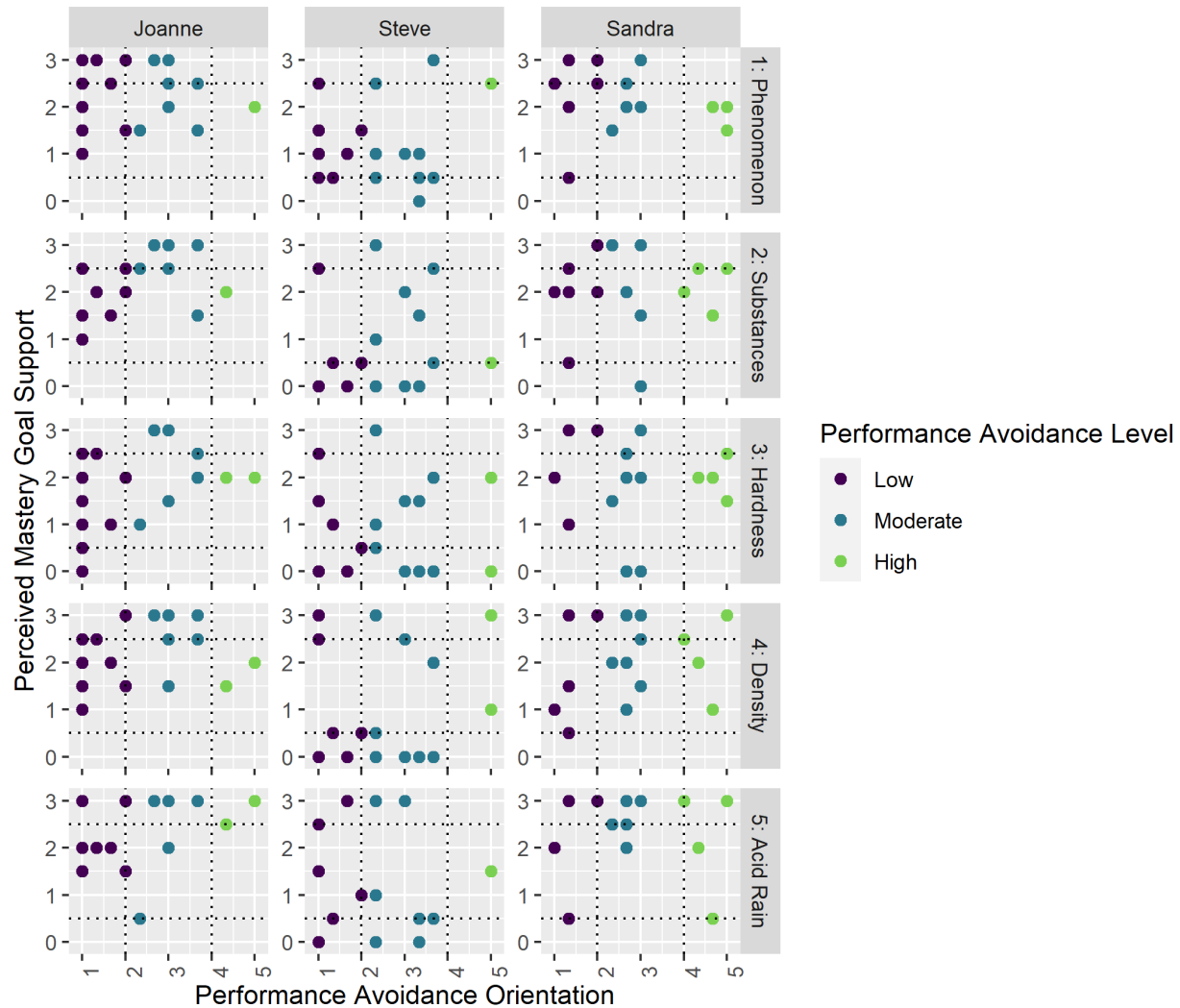
*Students' Mean Perceived Teacher Mastery Support by Mean Personal Performance-Approach Goals, by Teacher and Focal Lesson*



*Note.* Each dot represents an individual student. Personal performance-approach goal orientation was an initial measure prior to the focal lessons. Lines designate our boundaries for low, moderate, and high levels on each scale. For personal performance-approach goal orientation: low  $\leq 2$ , moderate = between 2 and 4, high  $\geq 4$ . For perceived teacher mastery support: low  $\leq 0.5$ , moderate = between 0.6 and 2.4, high  $\geq 2.5$ .

**Figure 5**

*Students' Mean Perceived Teacher Mastery Support by Mean Personal Performance-Avoidance Goals, by Teacher and Focal Lesson*

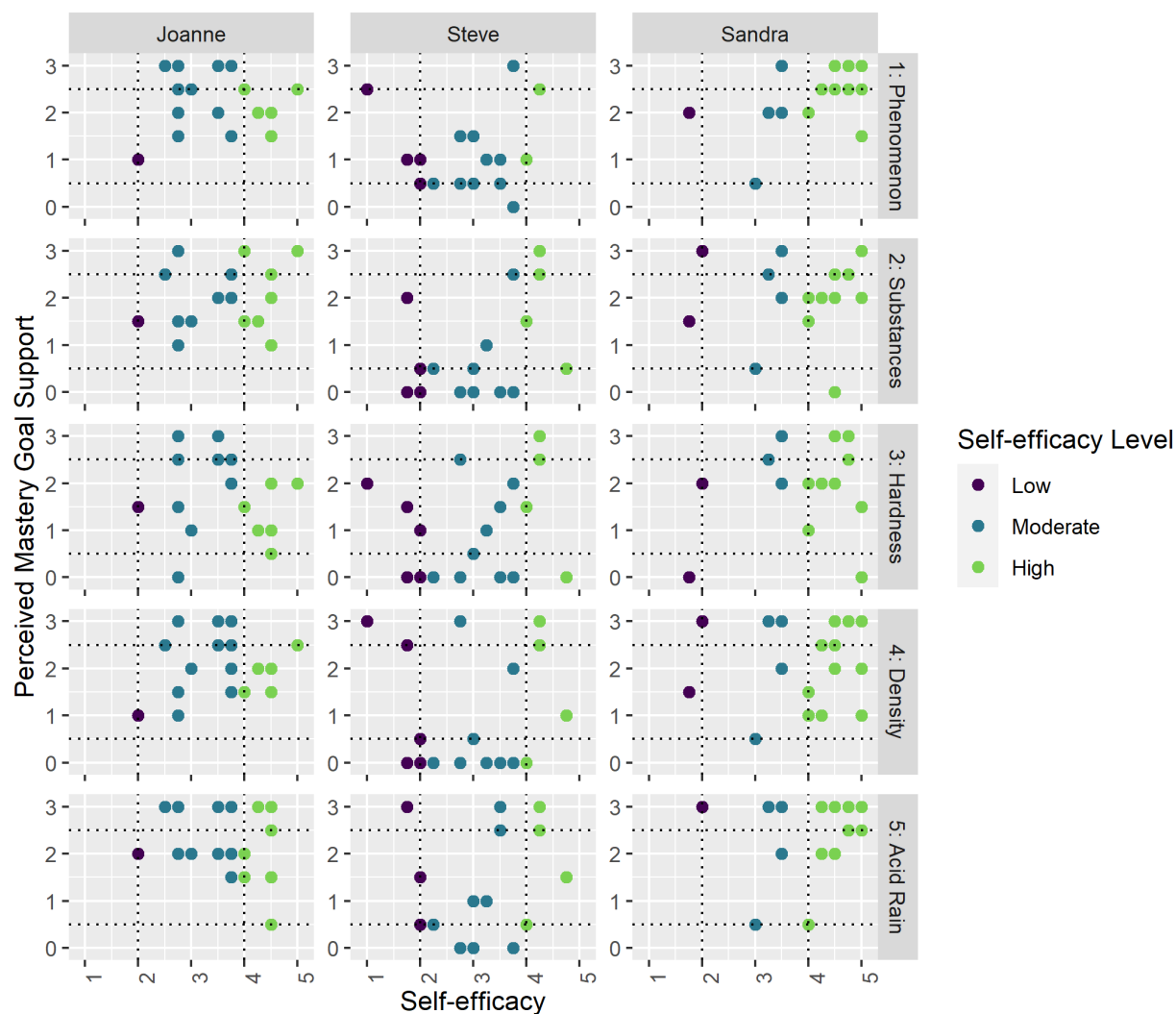


*Note.* Each dot represents an individual student. Personal performance-avoidance goal orientation was an initial measure prior to the focal lessons. Lines designate our boundaries for low, moderate, and high levels on each scale. For personal performance-avoidance goal orientation: low  $\leq 2$ , moderate = between 2 and 4, high  $\geq 4$ . For perceived teacher mastery support: low  $\leq 0.5$ , moderate = between 0.6 and 2.4, high  $\geq 2.5$ .

**Figure 6**



*Students' Mean Perceived Teacher Mastery Support by Mean Self-Efficacy, by Teacher and Focal Lesson*



*Note.* Each dot represents an individual student. Self-efficacy was an initial measure prior to the focal lessons. Lines designate our boundaries for low, moderate, and high levels on each scale. For self-efficacy: low  $\leq 2$ , moderate = between 2 and 4, high  $\geq 4$ . For perceived teacher mastery support: low  $\leq 0.5$ , moderate = between 0.6 and 2.4, high  $\geq 2.5$ .

### Case Narrative #2: Steve

Steve had taught for all 24 years of his experience at School A (64% FRPL; 59% non-

Hispanic White), where his classroom was next to Joanne's. The two collaborated closely on their planning. Steve held a bachelor's degree in chemical engineering and a master's in education. His focal class was his second hour class, with 32 students (research sample:  $n=21$ ).

### *Following Up for Academic Press and Accountability*

Steve emphasized classroom discourse focused on scientific understanding. Scientific definitions and explanations, the correct answers to questions, and sometimes the underlying purpose or learning goal of **tasks** in Steve's class were clearest to the coders, often because he asked students multiple follow-up questions to ensure accuracy or completeness of answers. For example, in the phenomenon lesson (V1), Steve used follow-up questioning when soliciting observations of a match to help students understand why certain kinds of observations were preferable to others. When a student offered "little," Steve responded, "What does little mean?" As other students chimed in, Steve continued to counter their responses with questions like, "What does small mean?...HOW small?...If I say 'small,' is my definition different than your definition?" until the students arrived at a specific measurement of the match. Steve explained that unlike the general adjective "small," a measurement always has the same meaning to everyone, "so saying something like that is more precise."

Steve would also often follow up repeatedly with the same student, either to allow the student to give a more complete answer or, in his own words, to not "let them off the hook" without responding, which served to emphasize accountability for learning. For example, when recapping the differences between soap and fat in the substances lesson (V2), Steve called on a student who did not seem to answer right away; when another student's hand shot up instead, Steve continued looking at the first student and rubbed his fingers together as a hint until the student said, "Texture." Steve then followed up with the same student with additional questions:

“Yeah, how did the soap feel? How did the fat feel?”

It was more common for Steve to follow up for precision or as an accountability strategy than to probe for scientific reasoning in a fully mastery-supportive way, although there were some examples of the latter. For example, when Steve’s class discussed the question, “If you had a ton of feathers or a ton of bricks, which one weighs more?” and a student, Peter, said he did not understand why the answer was “the same,” Steve invited the other students to try to explain it. Once Peter said that he now understood the answer, Steve additionally pressed him, “Why?” to get him to explain it in his own words.

### *A Culture of Question-Asking*

Perhaps because of the overall prevalence of questions and follow-up questions, multiple students in Steve’s class initiated their own questions on numerous occasions. In all five of Steve’s videos, students asked him spontaneous questions related to the science concepts they were learning. For example, in the substances lesson (V2), Steve distributed the same vocabulary sheets that Joanne had given her students. In the course of reviewing the definitions as a class, Steve’s students asked whether density explained why a tree floats in water and if hardness was related to why some drill bits are tipped with diamonds. Peter also challenged Steve’s assertion that a stick of chalk has the same mass when crushed into a powder, and Steve allowed Peter to conduct an independent investigation at the back of the room to test it.

Steve’s students may have felt encouraged to ask him questions because Steve himself embodied a scientific persona and often demonstrated his own positive affect toward academic **tasks** and scientific concepts. He framed one lesson by telling students, “It’s gonna be the best thing ever...we’re going to use math! YAY! And computational thinking! Double math day! Best ever!” Although he seemed to be slightly exaggerating his enthusiasm to provoke a response in

students, his overall sentiment seemed genuine, as it was consistent with other moments when he modeled enthusiasm and curiosity.

### ***Relating to, and through, Science***

Steve leveraged his interest in science as a way to engage **socially** with students. In three out of the five videos, he entertained tangents that varied in their relationship to the focal content of the lesson but were all related to science or technology in the real world (e.g., the switch from tin cans to aluminum cans). One notable example from the density lesson (V4) involved a discussion of the multiverse and time travel:

Steve explains that people used to say the fourth dimension was time, but now they think about it in terms of the “different numbers of the multiverse...quantum physics has gotten really confusing about this.” He explains that traveling from the classroom to the nearby McDonald’s requires traveling through both space and time: “Can I travel there instantly?” Someone seems to think so, and Steve says, “I wish I could—I’d be like Nightcrawler then.” A student asks if that means that inventing a time machine would require figuring out how to make time go faster, and Steve agrees, “Or slower.” He explains that if the student could make the trip from here to McDonald’s “take less time for you, for everyone else it would appear you got there like that.” He snaps his fingers. The class is very quiet—unusually so, for them—and Steve observes, “Time travel always bends people’s minds.” Two students have their hands raised. One asks whether time travel exists. The other asks, “Doesn’t time not exist, just our perception of it?” Steve: “No, time exists. And actually, to go back to the question ‘Does time travel exist,’ technically it does. We are technically traveling in time right now, just at one speed. We can’t change it.”

In addition to demonstrating how Steve incorporated science as a conversational topic in his class, the above excerpt also shows how Steve linked that scientific content to students' experiences as a way to foster positive **social** relationships with them. He used McDonald's as a location that students were familiar with, and he alluded to the teleporting X-Men character Nightcrawler.

Steve's attentiveness and involvement with students helped him draw on his knowledge of students to make these personally relevant connections. From small moments like complimenting a student's shoes or privately welcoming back another student after a prolonged absence, to more extended descriptions of his photography work at school sporting events where students from class were competing, Steve demonstrated that he was aware of students and aspects of their lives that were not directly related to being students or to science class. He spent some time in the acid rain lesson (V5) acknowledging students' concerns and questions about COVID-19; when he overheard a student saying she was scared, he told the class he wanted to address the virus "because I don't want people to be super scared or panicked" but also acknowledged his own concerns about his father's health risks. This was consistent with other moments of self-disclosure that could have made Steve more relatable to students, such as when he described his own experience having to use an eyewash fountain after a lab mishap.

### *A Social Climate of Boundary-Testing*

Although Steve used some positive community-build strategies, we found the overall **social** climate and tone of his class somewhat ambiguous at times, with Steve's style of humor and use of sarcasm potentially contributing to this feeling. The classroom banter that was common in Steve's class seemed poised on a delicate balance where some students might happily give and take while others could feel uncomfortable and perceive the banter as

combative. We did not see clear video evidence of student conflict or offended feelings but felt they were plausible outcomes of several exchanges. For example, when students tried to explain the feather/bricks question to Peter in the density lesson (V4), one student was visibly exasperated: fidgeting in his seat, gesturing emphatically with his arms while groaning, “IT’S A TON OF EACH MATERIAL.” When the root of the misunderstanding was revealed—that Peter had not known that a ton was a unit of measurement and not just a colloquial term for “a lot”—another student, William, said, “You didn’t know that?” in an incredulous tone. In the same lesson, William and Peter were involved in other peer interactions where their roles of instigator and target were reversed.

Similarly, Steve sometimes allowed students to tease or lightly mock him, or deliberately riled them up. For example, in the feather/bricks discussion, Steve responded to William’s incredulity by explaining, “That’s just a matter of what you’re exposed to, it’s not [Peter’s] fault. William, I could tell you all kinds of things that you’d be like, ‘I didn’t know that.’” William then promptly said, somewhat mockingly, “I didn’t know that,” which Steve seemed to parry acceptingly: “There you go.”

This mutual teasing dynamic seemed tenuously balanced because it was not always predictable whether Steve would accept or penalize a joking comment. In one lesson when a student asked to borrow a pencil because “my dad ate mine,” Steve replied, “He did not—don’t lie,” and wrote the student’s name on the board as part of his disciplinary system. He then said that he was out of pencils but later handed one to a different student who asked. Likewise, there was some inconsistency in Steve’s enforcement of rules and policies. During one investigation, he immediately deducted a point from a student for not wearing safety goggles, but five minutes later reminded a different student about the goggles rule without deducting a point. As a result,

the social dynamics in the class seemed to be characterized by students testing the boundary of what they could get away with.

### *An Emphasis on Teacher Control*

This dynamic of testing boundaries was made highly visible and potentially reinforced by Steve's stance toward **authority**. Steve used some classroom management strategies that were more autonomy-supportive, such as counting down from three to get the class's attention, but his other strategies were more authoritarian and often publicly identified the offending student, such as calling them out by name or writing names on the board for warnings and then adding tick marks to escalate the consequences. Steve used the threat of being written up on the board as a nonverbal cue to keep students in line: he would often stand and look pointedly at a particular student, twisting the cap of his dry-erase marker until the student ceased the offending behavior. Steve also had a solo desk at the side of the classroom that he used to relocate (in V2) or threaten to relocate (in V4) a student—the same student, in both lessons.

Consistent with this authoritarian approach to management, Steve's control of the conceptual aspects of class was evident in multiple dimensions of his **task** structure. The substances lesson (V2) and nearly all of the density lesson (V4) occurred in a whole-class modality. Group work was largely reserved for carrying out investigations, such as in V1, V3, and V5. The combination of Steve's apparent proclivity for teacher-centered instruction and his academic press strategies led to a paradoxical variability in his **task** difficulty: some activities were overly scaffolded, but others were quite challenging. For example, when Steve's students wrote C-E-R paragraphs in the hardness lesson (V3), Steve raised the level of both challenge and support by reviewing the criteria for an effective C-E-R paragraph with students beforehand and then inviting students to evaluate a peer's paragraph according to those criteria after they had all

attempted to write their own. However, in V1 Steve heavily scaffolded the phenomenon investigation by leading the class through the procedures step by step.

Although Steve infrequently mentioned **time** concerns or appeared to rush students, this may have been because he led so much of the class time; the control over timing was implicit. He also mentioned some type of formal **evaluation** in every video, often to enforce task engagement or compliance, such as hinting that a quiz might be coming up or threatening to deduct points for violating safety procedures. These references to evaluation could undermine mastery goals both by suppressing students' autonomous engagement and by highlighting performance over developing mastery.

Steve did seem to be working toward greater support for student **autonomy**. On multiple occasions—possibly in response to feedback he was receiving from us—he attempted to give students more autonomy but usually ended up undermining, revoking, or simply forgetting about those autonomy provisions. For example, in the density lesson (V4), Steve invited groups to select a representative to collect and pose vocabulary questions from the group as Steve read a text aloud, but he then only solicited vocabulary questions once, early in the reading. There were some exceptions to the constrained autonomy, such as Steve's encouragement of Peter conducting his independent chalk investigation in V2. Notably, however, only one student received this autonomy support.

### ***Sarcasm and Mixed Messages***

Steve seemed to try to use different participation structures during academic **tasks** to hear from a variety of students, but his authoritarian management style and use of sarcasm could have undermined the mastery-supportive potential of these strategies. Although Steve often seemed intentional in his use of sarcasm as a way of building rapport with certain students whom he



believed could “handle” it, we noted that other students might observe a sarcastic exchange and feel nervous about being on the receiving end in the future, even if they were “safe” from being such a target in Steve’s mind.

For example, in the density lesson (V4), as Steve was reading aloud, he cold-called two students to respond to reflection questions in the reading and then was sarcastic when they could not answer, attributing the failure both times to students’ lack of attention. At other times, he was gentler with the cold-call, most notably in the acid rain lesson (V5), where he seemed the most relaxed, good-humored, and supportive in his interactions with students. In that lesson, he allowed students who could not answer right away to confer in their groups and additionally asked everyone to discuss the question in the groups, resulting in less of a spotlight on the original student. However, on other occasions he may have undermined these more supportive accommodations through his style of humor: in one lesson where Steve set up a warm call by having students discuss a question in groups first, he reconvened the class by saying, “Who will I pick on?”

Combined with these features of participation, Steve’s patterns of public, and sometimes sarcastic, **recognition** of students could have focused them on producing correct answers and/or otherwise complying with expectations to avoid negative recognition or punishment, rather than on pursuing mastery. At times, Steve’s recognition felt implicitly socially comparative by casting students into classroom “roles.” For example, Steve publicly named two students as sharing his joy in the “double math day,” and in a different lesson he called one of these students “the smart one” when she, among the many students offering suggestions, gave the correct keystroke to zoom in on his computer display. By contrast, some students frequently received public negative recognition, such as the student whose seat was moved in two of the five lessons.

Steve also sometimes sent mixed **messages** to students about whether the goals of their classroom interaction were related to mastery or performance. We coded multiple occasions when Steve conveyed an explicit message to students that could be relevant to mastery goals but then undermined that message either through words or actions. This was perhaps most striking in the density lesson (V4), when Steve engaged the students in what was otherwise the highly mastery-supportive activity of explaining the feather/bricks questions to Peter, but tried to preempt negative peer comments by voicing those comments himself: “Who can explain to Peter without being rude about it? Being rude would be saying like, ‘what, are you stupid?’ Don’t say something like that.” Conversely, Steve openly praised Peter (and gave him candy) for being “brave enough to share” his C-E-R paragraph in the hardness lesson (V3) and for “stepping out of his comfort zone.” This came at the end of a lesson that Steve had begun by explaining his participation in the research project to students, telling them, “My job is to give you the best education I can...if there’s a tool I can use that will help you improve your education and learn the science better, absolutely I’ll use it” but then immediately caveated, “as long as it’s in my comfort zone.” Thus, students received mixed messages in this lesson about the value of leaving one’s comfort zone, an integral process for developing mastery.

### ***Summary***

The features of Steve’s classroom that aligned with mastery goal structure included his support for scientific understanding and his modeling and encouragement of scientific curiosity and questioning that occurred in every lesson. He also took advantage of opportunities in a few lessons to convey explicit messages to students about the value of stepping outside one’s comfort zone and the normalization of mistakes or lack of knowledge. However, these mastery-supportive practices co-occurred in nearly every lesson with practices within the recognition,

authority, and social categories that could potentially undermine mastery perceptions by creating an intimidating classroom environment where some students may have felt unsafe taking risks or making mistakes in service of gaining knowledge.

### **Student Perceptions of Steve's Mastery Support**

#### ***Overall Teacher Mastery Support Perceptions***

Steve's students, on average, perceived teacher mastery support below the mid-point of the scale in each lesson (Table 6). Mean teacher mastery support perceptions were highest in the acid rain lesson (V5) and lowest in the substances lesson (V2). The standard deviations for perceived teacher mastery support in Steve's class were the largest among the three focal classrooms, indicating substantial variation in student perceptions. Several students rated Steve's mastery support at the minimum value in the substances (V2), hardness (V3), and density (V4) lessons, but there were also a few students in every lesson who perceived high teacher mastery support (Figure 2). Perceptions of teacher mastery in the acid rain lesson (V5) still covered the full range of values but had fewer students clustering at the bottom end of the scale.

#### ***Teacher Mastery Support Perceptions by Initial Mastery Goals***

Similar to the overall pattern (Figure 2), low and high perceptions of teacher mastery support were reported by students at all levels of initial mastery goal orientation (Figure 3). The largest proportion of students who perceived low teacher mastery support were students with moderate initial mastery goals, with the pattern especially evident in the substances (V2), hardness (V3), and density (V4) lessons. In the substances (V2), density (V4), and acid rain (V5) lessons, there was a striking floor/ceiling distribution of perceived teacher mastery support, with relatively few moderate ratings. In V2, the moderate ratings tended to come from students with high initial mastery goal orientation, but in V4 and V5 they tended to come from students with

low and moderate initial mastery goals. Again, the data conveyed polarized perceptions in Steve's class: some students perceived high teacher mastery support and others low mastery support, with little middle ground; this occurred at all levels of initial mastery goals.

### ***Teacher Mastery Support Perceptions by Initial Performance Goals***

Most of Steve's students had low initial performance-approach goal orientation, and those students' perceptions of Steve's mastery support varied quite a bit (Figure 4). However, the four students with moderate initial performance-approach goals consistently perceived low teacher mastery support; none of these students ever reported teacher mastery support above 1 (on a scale of 0-3) for any lesson. Of the two students with high initial performance-approach goals, one fluctuated from moderate to high perceived mastery support and the other fluctuated from low to moderate perceptions.

Students across all levels of initial performance-avoidance goal orientation varied in their perceptions of teacher mastery support and tended to cluster at the extremes, with little middle ground (Figure 5). This pattern was especially visible in the density (V4) and acid rain (V5) lessons.

### ***Teacher Mastery Support Perceptions by Initial Self-Efficacy***

As with the other configurations of data, students at all levels of initial self-efficacy varied in their perceptions of teacher mastery support across the five lessons (Figure 6). However, there was some evidence of an overall positive relation between initial self-efficacy and perceived teacher mastery support in Steve's class. Students with low and moderate initial self-efficacy tended to perceive lower teacher mastery support, with a noticeable floor effect of multiple students in both groups clustering at the minimum value of the scale in the substances (V2), hardness (V3), and density (V4) lessons. By contrast, two of the four students in Steve's

class with higher initial self-efficacy rated teacher mastery support high in four out of the five lessons, the exception being the phenomenon lesson (V1) where two of these students were missing data. Although the small group sizes made interpretation difficult, there seemed to be a more apparent linear trend when we viewed perceptions of teacher mastery support by initial self-efficacy compared to initial mastery goal orientation.

### ***Key Findings and Variation by Lesson***

The substances lesson (V2) yielded Steve's lowest perceptions of teacher mastery support, especially among students who were initially low or moderate in mastery goal orientation, moderate in performance-avoidance goal orientation, and low or moderate in self-efficacy. However, students with higher initial mastery goal orientation as well as self-efficacy seemed to find the lesson more mastery-supportive. Our qualitative coding did not necessarily distinguish this lesson from others in terms of Steve's inconsistent or mastery-undermining strategies, but one distinction could have been that this was the one lesson that was conducted entirely in teacher-led whole-class format, except for Peter's independent chalk investigation. The extended teacher-led review of vocabulary and concepts on a handout may have been perceived by many students as being low in mastery support. However, students with higher initial mastery goal orientation and greater confidence in their science abilities were possibly better able to perceive the conceptual review as mastery supportive and might even have been able to appreciate the vicarious learning afforded through Peter's investigation.

The density lesson (V4) was the other lesson where polarized perceptions of Steve's mastery support were especially apparent. Like the substances lesson (V2), the density lesson was conducted almost entirely in a teacher-led, whole-class format and the teacher-led instruction was focused primarily on key scientific terms and concepts. However, unlike in V2,

where the higher perceived teacher mastery support tended to come from students with higher initial mastery goal orientation and self-efficacy, the high perceptions of teacher mastery support in the density lesson occurred across all levels of students' initial mastery goal orientation, performance-avoidance goal orientation, and self-efficacy. One thing that distinguished the density lesson from other lessons in the qualitative coding was the extended tangent about time travel excerpted in Steve's case narrative. The connection of class concepts (even though not density per se) to "mind-blowing" real-world phenomenon could perhaps have prompted more perceptions of teacher mastery support across students with different initial goal orientations and self-efficacy.

Finally, although the acid rain lesson (V5) resembled the density lesson (V4) in yielding some polarized perceptions of teacher mastery support, it also had the highest perceived teacher mastery support on average and a more even distribution of perceptions across all values of the scale, with less of a floor effect compared to Steve's other lessons. This result was consistent with our qualitative coding of this lesson feeling the most comfortable from a social perspective and featuring more mastery-supportive variations on otherwise common strategies in Steve's repertoire (e.g., allowing students to confer after being cold-called).

### ***Case Integration***

The quantitative findings of polarized student perceptions of mastery support in Steve's class were consistent with our qualitative coding of his clear strengths in supporting mastery—such as the level of challenge and his own enthusiasm for and knowledge of science—alongside potentially mastery-undermining practices, notably in the social and autonomy categories. Notably, although there was some evidence that Steve's students with higher initial self-efficacy might have perceived higher levels of mastery support, the polarized perceptions and relatively

low levels of perceived teacher mastery support generally occurred across levels of initial goal orientations and self-efficacy. This suggested that students' initial goal orientations and self-efficacy were not necessarily the strongest predictors of perceived teacher mastery support; other factors independent of students' individual motivational beliefs might be at play to explain why Steve's teaching seemed to promote mastery perceptions for some students but not others.

However, the slightly more positive shift in perceived teacher mastery support in the acid rain lesson (V5) provided encouraging evidence that students' perceptions of mastery support did not calcify, even though Steve's earlier lessons had received such divergent responses from students. This suggests that minor changes to instructional practice may be able to shift students' perceptions of mastery goal support on a day-to-day basis.

### **Case Narrative #3: Sandra**

Sandra had 15 years of teaching experience but was fairly new to School B (66% FRPL; 95% Black), having taught there for a year and a half at the start of the 2019-20 school year. She held a bachelor's degree in business and a master's in elementary education. Unlike Joanne and Steve, Sandra was teaching an IQWST unit for the first time and in isolation from her peers and normal self-designed curriculum. Her focal class for data collection was her fifth-hour "STEM class," with 28 students (research sample:  $n=20$ ).

### ***Autonomy-Supportive Science Learning***

The dimension of mastery goal structure most evident in Sandra's classroom was her support for student **autonomy** and scientific curiosity, most notably through her use of a Driving Question Board (DQB). The DQB is part of the IQWST curriculum and a common tool within NGSS science instruction, but it featured the most prominently within Sandra's classroom out of the three. Sandra introduced the DQB in the phenomenon lesson (V1), and her students spent

time generating questions related to the phenomenon they had just observed when combining aluminum foil with copper chloride. Sandra encouraged students to continue adding their spontaneous questions to the DQB outside of dedicated lesson time for it, which led to students sometimes adding questions without Sandra prompting them to do so. On one occasion, two friends “raced” each other to the front of the room in their eagerness to post a question on the DQB. Sandra also referenced the DQB throughout the unit, as in the hardness lesson (V3) when she referred to a pending question on the board, saying, “Tomorrow someone’s going to help us with that question there and hopefully we can remove it off the board.”

Sandra’s students were able to get to the DQB in the phenomenon lesson (V1) because the lab took less time than it did in Steve’s and Joanne’s classes, in part due to Sandra’s implementation decisions. She spent 7 minutes having students collect and identify their materials and reviewing the overall objectives and some safety procedures before asking the students, “Do I need to go over the procedures or do we have it?” The students chorused, “We have it,” and she turned them loose to carry out the investigation in their groups, which they did over the course of 14 minutes. By comparison, some combination of instructions and safety review took 11 minutes in Joanne’s class and 9 minutes in Steve’s class, and they both needed about 20 minutes for the teacher-led, step-by-step facilitation of the investigation. The difference of about 10 minutes of instructional time was equivalent to the amount of time Sandra’s students spent generating and sharing out questions for the DQB.

The implementation of the phenomenon investigation in V1 was a prominent example of the broad **autonomy** that Sandra generally allowed her students. During investigations (i.e., in V1, V3, and V5), Sandra frequently encouraged students to problem-solve with each other or to refer to the written instructions to figure out the next procedure, rather than relying on her to



provide the answer. She also allowed students a fair amount of physical autonomy within the classroom, such as the “race” to the DQB. Likewise, Sandra did not tend to be controlling over minor issues like tardiness or a lack of classroom supplies.

### *A Climate of Mutual Respect*

Sandra’s classroom generally had a warm **social** climate and an atmosphere of mutual respect between teacher and students, even as some of Sandra’s classroom management strategies leveraged teacher **authority**. She consistently addressed students affectionately as “scholars” and said “please” and “thank you,” which softened some public behavioral redirection of students. For example, in one lesson she told a student, “I really like you but next time I’m going to have to ask you to go. It’s really disruptive. Can you please work with me here, dear?” In addition to occasionally sending students out of the classroom, Sandra also publicly mentioned calling students’ parents and moved students’ seats for behavioral reasons, including three students in one lesson. However, she also routinely stood at the door of the classroom at the beginning of every lesson, warmly greeting each student as they entered and often having a brief personal exchange if a student looked especially happy, tired, or downbeat.

Once class officially began, Sandra’s discourse with students primarily focused on the lesson. Apart from greeting the students at the door, there was little personalized interaction in her videos, such as making connections to students’ interests. In a notable contrast to the other two classrooms, Sandra did not address COVID-19 at all in the acid rain lesson (V5), which turned out to be the last in-person science class her students would have that year. Importantly, though, Sandra’s class did not feel authoritarian, in part because she demonstrated enthusiasm for the science content she was focused on. She often spoke with energy and expressed positive affect toward the **task**, such as in V4 when the students predicted that their density calculations

for different pieces of chalk should be the same and she responded excitedly, “Let’s see if we can make that happen!” Sandra’s students seemed to respond positively to her directness and academic focus, and they also generally treated each other with respect. There were a few examples of students joking around or teasing each other in ways that could potentially have provoked some discomfort, but these were brief and relatively mild.

### *Pressing for Reasoning: A Work in Progress*

In addition to her well-developed other supports for autonomy, Sandra seemed to be working on promoting students’ cognitive **autonomy** by providing academic press for reasoning and promoting student discourse in **tasks**, all of which is vital for scientific sense-making. However, these supports for cognitive autonomy and academic challenge were somewhat inconsistent, perhaps because of the difficulty inherent in quickly identifying and honing in on the aspect of a student’s response that will clarify a scientific concept. For example, in the following sequence from the density lesson (V4), Sandra repeatedly asked students for “elaboration,” but it was unclear to us what kind of elaboration she was seeking given how she ultimately concluded the exchange:

Sandra: “So our unknown block has the same density as the aluminum. So can we assume or can we say that density is a property?” Multiple students answer “yes” en masse.

Sandra: “Who can elaborate further?” Student A: “Because it didn’t change.” Sandra: “What didn’t change?” Student A: “It was the same for aluminum and the mystery.”

Sandra: “OK, but it didn’t change. Who can elaborate a little further?...We have a bigger block here, but it has the same density as aluminum. You told me it’s a property because it didn’t change. I need someone to tell me what didn’t change and how that relates to density?” Student B: “The density didn’t change even though the volume was larger and

so was the mass, the density stayed the same.” Sandra: “So the density stayed the same even though the volume and the mass of the substance changed. So, mass and volume are not properties but what is?” Multiple students: “Density.”

Sandra moved from an open-ended question that asked for elaboration and reasoning to a more leading, closed question that students chorally responded to with a single word. She also ended up doing more elaboration than the students did, but her explanation was somewhat circular: the fact that an unknown substance and aluminum have the same density is not in itself proof that density is a property; it relies on the assumption that the unknown substance is aluminum—an assumption which Sandra justified by saying that they had the same density.

On another occasion, Sandra asked for ideas about how to calculate density using known quantities of mass and volume in a data table and a student offered, “You can calculate 2 times 2.2 times 2.1 [the dimensions of the unknown block], then you can use that on the aluminum or iron [blocks] in grams and see which one it is.” This explanation, though somewhat muddled, demonstrated a nascent conceptual understanding of density as the ratio of mass to volume and also anticipated that the ultimate goal of the activity was to calculate density to identify the unknown block as aluminum or iron. However, Sandra replied hesitantly, “All right...sounds a little elaborate here for us, I don’t quite understand that, so you’re gonna explain that to me a little later. I like your thinking but we’re going to have to bring it down to 7<sup>th</sup>-grade level.” She pivoted to other students and ultimately praised the simpler response, “Divide them [mass and volume],” that a different student offered. Thus, although Sandra had begun with a more open-ended solicitation of ideas, she did not follow up on the first idea and instead concluded her questioning upon hearing the correct formula.

It was also unclear how accustomed the students were to Sandra’s requests for

elaboration. The open-ended questions that Sandra asked her students are key to NGSS expectations for scientific reasoning, as reflected in IQWST materials, but it was unclear whether Sandra's questioning strategies during the IQWST unit were consistent with her methods during the self-designed unit that had preceded it. We observed that Sandra's students sometimes seemed uncertain after she questioned them, suggesting that they might have interpreted her follow-up questioning as evaluative (i.e., a sign that they were wrong), rather than an effort to solicit reasoning and promote mastery. Ultimately, the coding process left us with a sense that Sandra asked for elaboration and followed up on students' responses because she understood how important such follow-up questions were for both student motivation and science learning. However, she may have still been developing the skills to deploy her questioning effectively for this chemistry unit and to communicate to students why she was pushing their discourse in this way.

### ***Mastery-Undermining Recognition Patterns***

As some of these questioning exchanges unfolded, the participation structure as well as Sandra's **recognition** patterns could have undermined mastery by activating awareness of social comparison and therefore making performance salient. Sandra primarily relied on student volunteers for participation and commented on multiple occasions that "I keep getting the same hands," but she did not deploy alternative strategies to elicit participation from different students. Her public identification of the students with raised hands as chronic participators could implicitly cast them as the "smart ones" or the "good students," in which case the strategy could have the opposite effect of its intention to get quieter students to take a risk and speak up.

Similarly, Sandra's neutral or uncertain response to certain student comments, as described above, stood in marked contrast to her trademark, decisive "Very good" when she

heard a correct answer or an answer closer to what she was expecting. Although positive and encouraging, recognition like “Very good” does not provide informational feedback to the student about what is good about the response, so it could convey an implicitly evaluative message that the comment is good because it is correct or because it is what the teacher wants to hear. Conversely, in the substances lesson (V2) when students were eagerly sharing out personal ideas (often quite funny ones) related to reading questions, Sandra responded only “Okay” to each comment before calling on the next student. She may have been attempting neutrality to avoid favoring some ideas over others, but this recognition pattern could undermine mastery orientations if students perceive the teacher’s neutral response to unconventional or creative student comments as negatively evaluative in comparison to the clear praise that she offered on other occasions to simpler, predictable, and/or correct answers. Such an interpretation could lead students to try to produce answers that will please the teacher and earn praise, rather than engaging in the messier kind of thinking and reasoning that comes with developing scientific understanding. We provided Sandra with feedback on her minimalist neutral recognition after V2, which may have contributed to her subsequent efforts to request more “elaboration” from students, as described above.

### ***The Need to “Move On” as a Driving Force***

Although there was some sense of flexible **timing** in Sandra’s class due to the time checks and modifications she conducted when students were working independently, she also made some allusion to “moving on” multiple times in most lessons. She also explicitly encouraged speed in the warm-up activity that led off the acid rain lesson (V5), telling students they were going to have “a little bit of competition” to answer the question, “What three ways can we represent chemical equations?” and announced the ordinal placements as teams produced

the correct answer. Although all teams ultimately received the same number of points, softening the competitive element, Sandra made social comparison salient by publicly proclaiming the order of completion, to which at least one student audibly complained, “That’s not fair.”

Sandra made little reference to formal **evaluation** overall, but when she did, she tended to enforce compliance over the understanding goals of the assessment, using points and public accountability. For example, in the hardness lesson (V3) she began class with a review of homework questions and provided a compliance rationale for the **task** rather than one focused on learning: “I am going to pick your brains right now to see who actually read, and I’m probably going to collect your packets too just to grade it to see if you’re completing the assignments.” These references to “moving on” and other compliance-related messaging contributed to an occasional feeling that the **task** sequencing prioritized coverage and completion of the curriculum over student understanding. Particularly in the last three videos, tasks sometimes lasted for only a few minutes before Sandra would introduce a new task without connecting it to what students had just done.

### *Summary*

Overall, Sandra’s students experienced a high degree of autonomy in relation to science learning, such as in asking questions and figuring out procedures, which would seem to support mastery goal endorsement. These patterns were often most apparent in lessons in which students carried out investigations (V1, V3, and V5), including making predictions before the investigation and revisiting the DQB afterwards. Although Sandra used some controlling management strategies in most lessons and occasionally seemed to promote compliance or completion, the overall climate in her class was consistently warm and respectful, and she engaged students in relatively challenging tasks focused on scientific sense-making. She also

seemed to be working toward promoting greater cognitive autonomy and academic challenge by pressing for students' evidence and reasoning. Her discourse strategies in this area were somewhat inconsistent across multiple lessons, perhaps due to the newness of the curriculum, which could have contributed to some potentially mastery-undermining recognition patterns.

### **Student Perceptions of Sandra's Mastery Support**

#### ***Overall Teacher Mastery Support Perceptions***

On average, Sandra's students consistently perceived the highest teacher mastery support among the three classes (Table 6). Perceptions of teacher mastery support were highest in the acid rain lesson (V5) and lowest in the hardness lesson (V3). Standard deviations for perceived teacher mastery support in Sandra's class fell in between Joanne's and Steve's. Sandra's students primarily clustered at the higher end of the perceived teacher mastery support scale, including a ceiling effect of multiple students reporting the maximum value, but with a couple of outliers at the lower end (Figure 2).

#### ***Teacher Mastery Support Perceptions by Initial Mastery Goals***

None of Sandra's students had low initial mastery goal orientation, and students with both moderate and high initial mastery goal orientation perceived high teacher mastery support (Figure 3). Though not a striking difference, there was some evidence that the lower perceptions of teacher mastery support tended to be from students with moderate initial mastery goal orientation, while students with higher initial mastery orientation perceived higher teacher mastery support. This pattern was most visible in the acid rain (V5) lesson.

#### ***Teacher Mastery Support Perceptions by Initial Performance Goals***

A slightly larger proportion of Sandra's class had moderate initial performance-approach goal orientation compared to the other two classes, but their perceptions of teacher mastery

support were similar to those of the students with lower initial performance-approach goal orientation (Figure 4). The main distinction between the two groups seemed to be that more of the students with low initial performance-approach goal orientation reported the highest teacher mastery support.

Sandra's class had a fairly even distribution of students at all levels of initial performance-avoidance goal orientation, but there were not particularly clear patterns in perceived teacher mastery support across these groups (Figure 5). As with initial performance-approach goal orientation, the students with low and moderate initial performance-avoidance goal orientation seemed to perceive fairly similar teacher mastery support across the lessons. Students with higher initial performance-avoidance goal orientation seemed to cluster at more moderate perceptions of teacher mastery support in the phenomenon (V1), substances (V2), and hardness (V3) lessons.

### ***Teacher Mastery Support Perceptions by Initial Self-Efficacy***

The majority of Sandra's students reported high initial self-efficacy (Figure 6). In combination with the high perceived teacher mastery support in Sandra's class, this made it difficult to identify patterns in the data, as the upper right corner of the plot was so densely populated. There did not seem to be major differences in perceived teacher mastery support between students with moderate vs. high initial self-efficacy; however, students with high initial self-efficacy generally rated the phenomenon lesson (V1) higher in mastery support than students with moderate initial self-efficacy, and there was more variation in perceived teacher mastery support for the density lesson (V4) among students with high initial self-efficacy.

### ***Key Findings and Variation by Lesson***

Perceptions of Sandra's support for mastery were lowest in her hardness lesson (V3).



This was somewhat consistent with our qualitative coding of this lesson, particularly social dynamics: this was the lesson in which Sandra moved three students' seats for behavioral reasons, and we observed some mixed student affect (e.g., heads down on desks). This lesson also featured the only instance we coded of Sandra being sarcastic: when a student struggled to answer a question, she first acknowledged that she may not have worded the question clearly but then added, "Or maybe you just weren't listening," prompting an "ooh" from some other students. Additionally, there seemed to be some minor bickering within lab groups during the hardness investigation, and several groups seemed to mix up the procedures the first time around and were corrected by Sandra in ways that were less autonomy-supportive than her usual practices in other lessons. For example, she looked at one student's data table and told him to measure something again without providing a rationale for the directive or feedback about the initial measurement.

The hardness lesson was also the first lesson where we began noting a somewhat fragmented feel to Sandra's sequencing of and rationale for lesson activities, but we also observed some similar qualities in other lessons that Sandra's students rated quite highly in teacher mastery support. In particular, we had noted a lack of task cohesion and student perspective-taking in the acid rain lesson (V5), but this lesson had the highest class-level mean perceived teacher mastery support and the greatest proportion of students (10 out of 15) reporting high perceived teacher mastery support. Overall, we felt that there was somewhat less alignment in Sandra's class between our qualitative coding of the lessons and the students' reports of teacher mastery support.

### ***Case Integration***

Sandra's case presented some deviation between our qualitative and quantitative

analyses; the storyline here did not seem as clear. Divergence between researcher and student perceptions of classroom features has a precedent in motivation research (Furtak & Kunter, 2012; Urdan, 2004b). It could be that the many strengths we noted in Sandra's teaching, including her strong support for student autonomy, her warmth, and her attempts to use discourse to push for student reasoning, contributed to her students' high ratings of her mastery support overall, even if some of her discourse strategies were still developing in the eyes of our research team. Alternatively, Sandra's students could have been responding to mastery supportive practices that were not well captured by our coding protocol.

Unique features of Sandra's class composition could also have factored into the divergent perceptions. Sandra's students tended to be high in initial mastery goal orientation and very high in initial self-efficacy. Her students with higher initial mastery goal orientation and self-efficacy also tended to perceive higher teacher mastery support. This could have contributed to the overall high ratings of teacher mastery support in Sandra's class and may have created a more receptive "landscape" for perceptions of teacher mastery support compared to the other two classrooms. Interestingly, there was more variation in students' initial performance goal orientation in Sandra's class compared to Joanne's and Steve's, but students' perceptions of teacher mastery support did not seem to vary much by these performance goals. This "null" finding for performance goals suggests that Sandra's inconsistent public responses to student ideas did not activate concerns about social comparison as we speculated, or that perhaps her other mastery supports were effective at mitigating the activation of students' personal performance goals (Ciani et al., 2010). The students' high initial mastery goal orientation and self-efficacy—as well as other, unmeasured, factors that may have contributed to their nomination for inclusion in Sandra's STEM class—may also have helped insulate them from

performance-related anxieties as their teacher worked through these novel discourse strategies.

Additionally, Sandra identified as Black, and her students were predominantly Black as well. Prior research has demonstrated an “attitude-achievement paradox” (Mickelson, 1990) in which Black students report higher self-efficacy and self-concept compared to other students, but these beliefs seems less aligned with measures of academic performance (Graham, 1994; Seo et al., 2019; van Laar, 2000). Our findings from Sandra’s case could be consistent with that trend, or they could point to the need to further develop AGT frameworks to capture classroom supports for mastery that may be more or less salient for students from different cultural backgrounds. For example, Sandra’s teaching persona strongly evoked the “warm demander” prototype identified in literature on culturally responsive pedagogy (Ware, 2006). We speculated that this contributed to the positive and respectful social climate of her classroom, even though we did not identify many overt examples of rapport-building. The “warm demander” persona also offers a potential interpretation for why Sandra’s students did not seem polarized in their perceptions of her mastery support even though she used some controlling classroom management practices. Just as the source of the climate in Sandra’s class was somewhat “intangible” to us, we should consider the messages of mastery that may have likewise escaped our perspectives as coders.

### **Cross-Case Discussion and Implications**

The mixed-methods multiple-case study design afforded us the opportunity not only to examine students’ perceptions of each teacher’s classroom goal structure, but also to identify key patterns that emerged when looking across the cases. Although we initially presented the cases with minimal comparison across teachers, the contrast between classrooms provided important additional context for understanding each goal structure, especially each teacher’s instructional

delivery and decisions that were unique from the base curriculum. Below, we summarize the key themes and interpretations that emerged through this cross-case comparison and contextualize them within existing literature.

### **Balancing Social and Autonomy Support with Academic Challenge**

Overall, our integrated analysis aligns with prior literature on the importance of perceived social support as a component of perceived mastery goal structure and perceived motivation support broadly (Anderman et al., 2011; Patrick et al., 2011; Turner et al., 2002; 2013).

Perceived mastery support was generally high for Joanne and Sandra, whose classroom climates were warm and mutually respectful, and there was generally agreement across students about these teachers' mastery support, suggesting that strong social supports might help perceptions of mastery support converge among students with different personal goal orientations and self-efficacy. By contrast, perceptions of mastery support in Steve's classroom were lower and more varied; indeed, the plots of perceived teacher mastery support were almost inverted between Steve's and Sandra's classes, particularly for the phenomenon (V1) and density (V4) lessons (Figure 2). These lower ratings of teacher mastery support could reflect our observation that the social dynamics in Steve's class were more mixed than in Joanne's and Sandra's, in part because of his public recognition practices and use of sarcasm. Such a pattern would be consistent with prior associations found between teacher's use of sarcasm and lower levels of perceived teacher motivation support (Patrick et al., 2001; Turner, 2014).

Joanne and Sandra also used more autonomy supportive practices than Steve did, making the higher perceptions of teacher mastery support in their classrooms consistent with literature documenting the importance of autonomy support for mastery goal orientation (Ames, 1992; Elliot & Hulleman, 2017) and prior findings on the role of autonomy support in enhancing

multiple dimensions of students' perceptions of their learning environment (Benita et al., 2014). A key difference between these teachers was that Sandra's autonomy supports included self-directed student questioning and sense-making consistent with NGSS-aligned instructional design principles (NextGenScience, 2021; Schwarz et al., 2017), whereas Joanne's autonomy supports largely manifested in her approach to classroom management. However, prior research has found that middle schoolers may interpret teacher supports for autonomy in relational terms (Wallace & Sung, 2017), suggesting an alignment between the autonomy and social categories of the TARGET+3 framework. In other words, Joanne's autonomy-supportive classroom management procedures could have contributed to her students' (and our) perceptions of a consistently warm classroom social climate and strengthened their perceptions of mastery goal structure. By contrast, even though Steve's classroom also featured student questioning, his more controlling classroom management style could have contributed to his students perceiving less social support and consequently less support for mastery goals.

However, strengthening mastery perceptions may require balancing social and autonomy supports with challenging academic work, in keeping with literature on the importance of teachers' instructional and emotional support for student achievement and motivation (Mantzicopoulos et al., 2018; Song et al., 2015). Joanne's case in particular suggests that achieving this balance might be especially important for students with higher personal mastery goal orientation and self-efficacy, since these students tended to perceive more moderate teacher support for mastery compared to their peers. This interpretation is consistent with prior work showing that promoting higher-order thinking is an important component of mastery-supportive classrooms (Morrone et al., 2004). Steve's more academically challenging approach yielded some high perceptions of mastery support across all levels of initial personal achievement goals

and self-efficacy, but again, the other features of his goal structure may have contributed to the polarized student perceptions in his class.

Sandra's case offers a glimpse of a teacher working to develop an optimal balance between academic challenge and social support to foster the kind of student-driven science learning described by the NGSS. We perceived Sandra's class as generally falling somewhere in between Joanne's and Steve's in the level of challenge, in part due to her inconsistency in facilitating higher-level scientific discussions. However, her autonomy supports included practices like the Driving Question Board, which aligns with NGSS goals of students co-creating questions to investigate and then devising and enacting plans to answer those questions in collaboration with their classmates and teachers (NRC, 2012; Schwarz et al, 2017). Sandra's warm and respectful classroom climate, similar to Joanne's, may have helped her students to feel comfortable and capable while asking and answering these questions. In turn, Sandra's students were fairly unified in perceiving high levels of teacher mastery support, without the decline among students with higher initial mastery goal orientation and self-efficacy observed in Joanne's class. The consistent social and autonomy supports in her classroom may have mitigated her inconsistent efforts to challenge students, leaving her students better able to recognize her overall focus on mastery-oriented science learning. This interpretation would be consistent with prior work suggesting that students' experiences of teacher support early in the school year may converge with perceived mastery goal structure (Turner et al., 2013). Importantly, Sandra's case further demonstrates that the theoretical components of mastery goal structure, taken together, may present an unrealistic or unnecessarily high standard for teachers to meet if they have a sufficient foundation in each component. While Sandra's practices did not perfectly align with "optimal" enactment of every TARGET+3 category, she did not have to be

perfect for her students to perceive high support for mastery in her classroom, which is the desired outcome of a mastery goal structure.

The cases also present evidence that lesson-level variations in teachers' practice can shift students' perceptions of mastery support, a finding that supports the previously documented malleability of classroom goal structures (Linnenbrink, 2005) and holds important implications for building teachers' capacity to more consistently enact mastery supportive practices. For example, Steve's students had relatively more favorable perceptions of mastery support in his acid rain lesson (V5), which featured more autonomy-supportive practices than usual, such as including a peer support component in his cold-calling. The alignment of Joanne's students' lower perceived mastery support in the hardness lesson (V3) demonstrated students' potential sensitivity to teachers' usual mastery supports slipping. Thus, an implication of this work is recognizing the importance of teachers receiving feedback about lesson-level variations in students' perceptions of mastery to identify strategies that promote or undermine students' recognition of mastery goal structure in the classroom and, possibly, students' personal endorsement of mastery goals.

### **Mutually Reinforcing Personal Achievement Goals and Classroom Goal Structures**

All three cases present evidence of a mutually reinforcing relationship between personal achievement goals and classroom goal structures. Due to the timing of data collection, the learning environment created by each teacher could have already shaped students' personal achievement goals and self-efficacy by the time the "initial" measures were taken a few months into the school year. In other words, the students' goal orientations and self-efficacy were plausible outcomes of the observed classroom goal structures as well as potential predictors of students' reactions (Friedel et al., 2010; Senko et al., 2012).

Viewing the students' personal achievement goal orientations as outcomes affords a clearer potential interpretation of the performance goal orientations in particular. There were not distinctive patterns in perceived teacher mastery support across either performance-approach or performance-avoidance goal orientations, but the distributions of the performance goal orientations in the three classes could reflect social comparison consequences of each teacher's recognition and classroom management practices. Steve's students had, on average, the highest initial performance-approach goal orientation among the three classes, as well as moderate initial performance-avoidance goal orientation. Steve's academically challenging class, combined with recognition practices that could undermine student autonomy, such as cold-calling and leveraging of formal evaluation for control, could have heightened students' awareness of how "smart" or "stupid" they appeared relative to their peers. (It is also notable that Steve's students had, on average, the lowest initial self-efficacy among the three classes.) By contrast, Joanne's egalitarian participation structures and downplaying of competition from the beginning of the school year may have contributed to her students having, on average, the lowest performance-avoidance and performance-approach goal orientation, consistent with literature on classroom practices that can mitigate the uptake of performance goals (Ciani et al., 2010; Song et al., 2015).

The fact that Sandra's students had relatively high performance goal orientations compared to Joanne's and Steve's, along with high mastery goal orientation and self-efficacy, also highlights a possible effect of the inconsistency we observed in Sandra's mastery supports. It is possible that Sandra's still-developing feedback and recognition practices—such as the clear praise of correct answers, reliance on "the same hands," and occasional emphasis on speed or completion—could have activated students' performance-approach or performance-avoidance goals even as her other practices promoted their mastery goals and self-efficacy. Her recognition



practices could have differentially influenced students' performance goals depending on whether the students interpreted her feedback as emphasizing social comparison or instead as a sign of her confidence in their abilities and her emphasis on developing their scientific understanding as the goal of classroom interactions (Smart, 2014).

Additionally, even if some of Sandra's practices did promote performance goals, prior research suggests that her concurrent strong support for mastery could make her classroom an overall supportive environment for student motivation and achievement (Linnenbrink, 2005), especially when considering the approach to embedded assessment and evaluation promoted by NGSS-aligned design principles (NextGenScience, 2021). Sandra's authoritative identification of correct answers after her more open-ended attempts to solicit students' ideas and explanations could reflect instructionally responsive patterns of discourse that may benefit students' science learning (Furtak & Shavelson, 2009; Scott et al., 2006) as well as motivation, especially if these discourse patterns are consistent with students' prior learning experiences in science (Furtak & Kunter, 2012). Sandra's students being relatively high on all the initial achievement goal and self-efficacy measures and high in perceived teacher mastery support poses an intriguing puzzle for further research to tease out the relative contributions of students' incoming motivational attributes versus teacher practices on students' uptake and endorsement of mastery goal structure in the context of science learning.

### **Other Factors in Goal Structure Enactment and Perceptions**

Finally, looking across the cases with an integrated comparative perspective reveals possible student and teacher factors underlying the goal structures we observed in each classroom. Although we can only speculate about the influence of these factors on the teachers' practices, the detailed case narratives raise important questions that we believe are novel in AGT

research and ripe for further exploration.

For example, Joanne had more students with individualized education plans in her class than the other two teachers, and the nature of their accommodations necessitated multiple teaching aides. This class profile could have factored into her use of questioning that made participation accessible to all students, especially in the whole-class setting, even if that led to a trade-off with academic challenge. Conversely, Sandra may have felt more opportunity to try out new discourse strategies with her STEM class. The fact that Sandra's students had to be nominated for the STEM class also cannot be ignored as a possible reason why they reported, on average, the highest initial mastery goal orientation and self-efficacy among the three classes. If these characteristics made students more receptive to mastery goal messaging, the class selection may have contributed to Sandra's high student ratings of teacher mastery support and the somewhat inconsistent alignment between our qualitative coding and the student report data compared to the other classrooms.

We also reiterate our observation from Sandra's case that the misalignment between the quantitative and qualitative results for Sandra's class could stem from factors such as racial and cultural effects that were not accounted for in the TARGET+3 observational framework or our survey measures, and/or that were not reflected in our research team. This discrepancy warrants further exploration and possible race-reimagining (DeCuir-Gunby & Schutz, 2014) of instruments and practices in motivation research. Doing so would enhance our ability to capture motivationally supportive practices and variations across multiple sociocultural contexts.

Teacher gender may have also factored into both the teachers' instructional practices and our interpretation of them. We noted, for example, that the warmer social climates were identified in the two female teachers' classrooms, and that both Joanne and Sandra affectionately

addressed their students as “dear” or “honey”—a practice that a male teacher may not have used as readily, or that might have been interpreted differently by an observer if it had occurred with a male teacher. To our knowledge, no studies have examined gendered patterns in classroom goal structures, but our findings about the importance of social climate in promoting student perceptions of mastery goal support point to the merit of exploring this question, given prior work identifying teacher gender as a potential factor in the quality and impact of teacher-student relationships (Cornelius-White, 2007; Spilt et al., 2012). It is also worth considering how gendered teaching practices might have intersected with gendered associations and patterns of underrepresentation within science as a discipline (OECD, 2020). In addition to being the only male teacher in our sample, Steve was also the only teacher with a degree in a scientific field (chemical engineering). His disciplinary expertise could have played a role in his ability to press students for scientific accuracy, make spontaneous relevance connections, and build rapport with students around scientific topics in class.

Although our teachers were highly experienced, they were also in the process of learning as we collected data, and the features of their classroom goal structures may have reflected some of the “growing pains” they were experiencing as learners. All three teachers were teaching the IQWST chemistry unit for the first time, meaning they had no feedback from prior students to inform their choice of instructional strategies. Their concurrent participation in professional learning about how to support student motivation also potentially encouraged them to try new strategies that they had not yet fully mastered. For example, we saw evidence that both Steve and Sandra attempted to respond to feedback they had received as part of the professional learning, but the adjustments to their practice were incomplete. Thus, it is important not to interpret the case narratives as representations of static classroom goal structures, but rather as evidence of the

difficulty in enacting mastery goal structures, the nonlinear progression of teacher learning, and the ongoing work and support needed from researchers and instructional developers to help teachers achieve consistency with mastery-supportive practices (Anderman & Klassen, 2015). A growing body of work in mathematics and science education research examines the factors underlying the wide variation observed in teachers' ability to facilitate student discourse focused on reasoning and sense-making that is central to the NGSS (e.g., Louie, 2020; Luna, 2018; Morrone et al., 2004; Richards et al., 2020); this work could be extended to examine the factors that contribute to teachers' uneven uptake of mastery-supportive practices.

### **Limitations and Future Directions**

Although our study design represents a novel approach in goal structure research, we acknowledge several limitations. Due to our collection of student data from only three classes, the types of quantitative analyses we could use were limited due to limited degrees of freedom (Kim, 2005). In particular, prior AGT research suggests a need to use person-oriented approaches (e.g., latent profile analysis) to examine heterogeneous patterns of achievement goals (Wormington & Linnenbrink-Garcia, 2017), but we were not able to estimate structural equation models due to limited statistical power. We also did not have a true baseline measure of students' personal goal orientations and self-efficacy due to the survey being administered a few months into the school year, making it difficult to examine variation in perceived teacher mastery support across students' entering motivational beliefs. Finally, the COVID-19 pandemic prevented us from collecting post-unit data, which could have contributed to a better understanding of changes in students' goal structure perceptions over time (Turner et al., 2013).

To address these limitations, we recommend several future directions. One future direction would be to replicate this study with a larger sample of students across multiple

teachers, which would allow for person-oriented analyses and examination of how heterogeneous achievement goal profiles relate to students' perceptions of classroom goal structure, as well as the study of goal structures in different teaching contexts. Future work could also take a true baseline measure of students' motivational profiles and measure perceived teacher mastery support at multiple time points over the year, including in different curricular units. These approaches could help to further pinpoint possible lesson-level influences on students' perceptions of classroom goal structure, such as the variable influences of negative social dynamics and experiencing academic difficulty, as well as to identify possible time lags between enacted teacher practices and student perceptions of the learning environment. Interviewing students could also yield more nuanced information about the classroom cues that students interpret as mastery supportive.

Within our qualitative strand, the video recording system focused on and followed the teacher, which constricted our ability to observe all students in the classroom throughout the lesson. Since the teacher wore the primary microphone, student audio was limited to the voices that were loudest or closest to the teacher at a given moment. The classroom is a dynamic system in which the teacher and students are continually reacting to each other. The limited perspective on the students therefore constrained both the sample of student behavior we could incorporate in our coding and our ability to interpret certain teaching practices.

It is also possible that the content and/or modalities of the lessons constrained the types of teaching practices we observed. Although we attempted to select a video corpus that spanned the unit and represented a range of instructional modalities, we ultimately restricted the data to five videos per teacher. Future work could explore patterns in classroom goal structure across different instructional modalities (e.g., whole-class, group work), activities (e.g., investigations,

discussions), or content (e.g., density vs. solubility) to identify various motivational affordances and limitations of these configurations.

We speculated in the cross-case discussion about factors beyond observable teaching practices that possibly influenced classroom goal structure but that we were unable to explore in depth. In addition to those factors, prior work has demonstrated a connection between science teachers' personal achievement goal orientations and their teaching practices (Bae et al., 2020). Future work could collect data, including interview data, on teachers' motivational profiles to contribute additional insights into this possible underlying influence on classroom goal structures and inter- vs. intra-classroom variations in goal structure.

### **Conclusion**

Our convergent mixed-methods approach highlighted the variability in classroom goal structures among three 7<sup>th</sup>-grade science teachers using the same base curriculum. The most notable differences were apparent in the way that teachers handled the relative balance of social support and academic challenge, often expressed through teachers' discourse patterns in following up on student answers and the degree of autonomy support in their classroom management and instructional practices. Triangulating these observations against student perception data suggested that a teacher's support for students' autonomy and socio-emotional needs, both overall between classrooms and on a day-to-day basis within classrooms, aligned with student perceptions of mastery goal structure. However, remaining within-classroom variation in student perceptions of mastery support suggests that students' personal achievement goal orientations and science self-efficacy may interact with lesson-specific goal structures to yield differential patterns of perceived master support. While further research is needed to test causal linkages between specific classroom stimuli and student perceptions of mastery support,

our findings suggest that teachers can shift their students' perceptions of the classroom goal structure in ways that could help more students endorse mastery goals and promote deeper science learning. Mastery goal structure is therefore something that teachers can work toward developing in their classrooms, making it both a manageable and important target for professional learning and growth in science education.

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The authors report there are no competing interests to declare.

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## Online Supplemental Materials

## Appendix A

*Summary of Dates, Core Instructional Activities, and Coding Assignments for Video Corpus*

|                               | Joanne                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Steve                                                                                                                                                                                                                                                                                                                                                            | Sandra                                                                                                                                                                                                                                                                                                                                                                                   |
|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Video #1 (V1)<br>“Phenomenon” | January 7, 2020 <sup>a</sup><br>– <b>Teacher poses warm-up/prior knowledge questions</b><br>– <b>Students create introductory phenomenon by combining aluminum foil with copper chloride</b>                                                                                                                                                                                                                                                                 | January 7, 2020 <sup>a</sup><br>– Teacher has students make “practice observations” of a match and reviews criteria of effective observations<br>– <b>Students create introductory phenomenon by combining aluminum foil with copper chloride</b>                                                                                                                | December 3, 2019 <sup>b</sup><br>– <b>Teacher poses warm-up/prior knowledge questions</b><br>– <b>Students create introductory phenomenon by combining aluminum foil with copper chloride</b><br>– Students generate questions for the Driving Question Board (DQB)                                                                                                                      |
| Video #2 (V2)<br>“Substances” | January 13, 2020 <sup>b</sup><br>– “Monday morning share”<br>– <b>Teacher guides students through a vocabulary sheet</b><br>– Students share out on <b>questions from Reading 1.1 (<i>What is Important about the Stuff I Use?</i>)</b><br>– <b>Teacher uses chalk to demonstrate concepts related to substances, mixtures, and properties</b><br>– <b>Teacher begins reading aloud Reading 1.2 (<i>What Makes a Substance a Special Kind of Stuff?</i>)</b> | January 13, 2020 <sup>b</sup><br>– Teacher reviews last week’s lessons<br>– <b>Teacher passes out vocabulary sheet and reviews the terms and concepts as he uses chalk to demonstrate concepts related to substances, mixtures, and properties</b><br>– <b>Teacher begins reading aloud Reading 1.2 (<i>What Makes a Substance a Special Kind of Stuff?</i>)</b> | December 6, 2019<br>– Small-group then whole-class discussion of <b>questions from Reading 1.1 (<i>What is Important about the Stuff I Use?</i>)</b> , completed for homework<br>– <b>Teacher uses chalk to demonstrate concepts related to substances, mixtures, and properties</b><br>– Students debate whether air is a substance or a mixture<br>– Students add questions to the DQB |
| Video #3 (V3)<br>“Hardness”   | February 5, 2020 <sup>b</sup><br>– Students brainstorm guidelines for choosing lab groups<br>– <b>Students conduct hardness investigation</b><br>– <b>Teacher reviews components of a Claim-Evidence Reasoning (C-E-R)</b>                                                                                                                                                                                                                                   | February 3, 2020<br>– Teacher talks to students about rationale for the research study<br>– <b>Students conduct hardness investigation</b><br>– <b>Teacher reviews components of a Claim-Evidence Reasoning (C-E-R)</b>                                                                                                                                          | January 13, 2020 <sup>b</sup><br>– Whole-class share-out on questions from homework reading (Reading 3.1, <i>Melting Points</i> )<br>– <b>Students conduct hardness investigation</b>                                                                                                                                                                                                    |



|                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                              | <ul style="list-style-type: none"> <li>– Each student independently writes a <b>C-E-R response to the question, “Is hardness a property of substances?”</b></li> </ul>                                                                                                                                                                                                                                                                                        | <ul style="list-style-type: none"> <li>– Students work at tables to compose a <b>C-E-R response to the question, “Is hardness a property of substances?”</b></li> <li>– Teacher asks for a volunteer to share their C-E-R for the class to evaluate</li> </ul>                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Video #4 (V4)<br>“Density”   | February 11, 2020 <ul style="list-style-type: none"> <li>– Students play drawing game on white boards</li> <li>– Teacher asks groups to draw a picture that represents the following “riddle”: <b>“What’s the difference between a pound of feathers and a pound of bricks?”</b></li> <li>– Students jigsaw <b>Reading 4.1 (<i>How Can Two Objects That Are the Same Size Have Different Masses?</i>)</b></li> </ul>                                          | February 10, 2020 <sup>b</sup> <ul style="list-style-type: none"> <li>– Teacher tells the story of Archimedes using water displacement to calculate the density of gold</li> <li>– Teacher reads aloud <b>Reading 4.1 (<i>How Can Two Objects That Are the Same Size Have Different Masses?</i>)</b> and provides direct instruction about density</li> <li>– Class recaps the question, <b>“If you had a ton of feathers or a ton of bricks, which one weighs more?”</b></li> <li>– Teacher guides students through a data table using the density formula</li> </ul> | January 28, 2020 <ul style="list-style-type: none"> <li>– <b>Teacher guides students through calculating the density</b> of three cubes (iron, aluminum, and unknown) and determining that the unknown cube is aluminum</li> <li>– Students calculate the density of chalk from yesterday’s investigation, discuss results, and answer lab reflection questions</li> <li>– Students begin <b>Reading 4.1 (<i>How Can Two Objects That Are the Same Size Have Different Masses?</i>)</b> in groups, to be continued for homework</li> </ul> |
| Video #5 (V5)<br>“Acid Rain” | March 12, 2020 <sup>b</sup> <ul style="list-style-type: none"> <li>– <b>Teacher fields questions from students about COVID-19</b></li> <li>– Teacher checks student homework (Frayer squares on <b>chemical reactions</b>)</li> <li>– <b>Teacher reads aloud Reading 8.1 (<i>Why is the Statue of Liberty Green?</i>)</b></li> <li>– Students write summaries of Reading 8.1 in groups</li> <li>– <b>Students set up “acid rain” investigation</b></li> </ul> | March 11, 2020 <sup>b</sup> <ul style="list-style-type: none"> <li>– Teacher guides students through a review of <b>chemical reactions</b>, reactants, and products using the equation for cellular respiration</li> <li>– <b>Teacher reads aloud Reading 8.1 (<i>Why is the Statue of Liberty Green?</i>)</b></li> <li>– <b>Students make predictions and set up “acid rain” investigation</b></li> <li>– <b>Teacher talks about COVID-19 and fields student questions</b></li> </ul>                                                                                 | March 12, 2020 <sup>b</sup> <ul style="list-style-type: none"> <li>– Competitive “activator” question in groups: What are 3 ways we can represent chemical equations?</li> <li>– Teacher recaps a prior demonstration of igniting magnesium and facilitates a whole-class exchange about how to represent that <b>chemical reaction</b></li> <li>– Class is interrupted by an announcement for students to clean out their lockers</li> <li>– <b>Students make predictions and set up “acid rain” investigation</b></li> </ul>             |

*Note.* Content or activities that overlap across multiple classrooms are bolded.

<sup>a</sup> Video was viewed by multiple members of the research team in creating preliminary analysis documents.

<sup>b</sup> Video was coded by two coders.

## **Appendix B**

### **Validation of the Short Scale for End-of-Class Report (ECR)**

The two items used as the Teacher Mastery Goal Support (TMS) scale on the End-of-Class Report (ECR) were selected from the Patterns of Adaptive Learning (PALS) scale for Perceptions of Teacher's Mastery Goals (Midgley et al., 2000). An adapted version of the full Perceptions of Teacher's Mastery Goal scale was included on a post-survey intended to measure students' perceptions of their teacher's support for mastery goals throughout the entire instructional unit. However, the closure of schools due to the COVID-19 pandemic prevented the administration of the post-survey in the focal classrooms for this analysis.

The participants featured in this analysis were part of a larger cohort of teachers who had attended the same professional learning institute. This cohort included three teachers in a different state whose implementation unit was earlier in the 2019-20 school year and whose students ( $n=121$ ) were therefore able to complete the post-survey, along with ECRs for 12 videorecorded lessons. While the post-survey and ECR scales were not completely equivalent, the post-survey data from these classrooms provided an opportunity to compare the full TMS scale on the post-survey with the two TMS items on the post-survey that paralleled the two-item TMS scale on the ECR, following procedures described by Gogol et al. (2014) for assessing the psychometric properties of short scales measuring motivational-affective constructs. The model-based reliability was  $\omega = 0.80$  for the full TMS scale on the post-survey and  $\omega = 0.71$  for the short TMS scale on the ECR, indicating that the full scale had adequate reliability and that the short scale measured the latent construct as measured by the full scale with adequate precision. The correlation of the short scale with the full scale was  $r = 0.93$  and, when corrected for

overlapping error variance (Levy, 1967), was  $r = 0.56$ , indicating that the short scale substantially reproduced the information in the full scale.

Finally, the short and full TMS scale were correlated with other motivational scales on the post-survey and with students' science achievement scores. In all cases, the absolute difference in correlation between the short and full TMS scale with each other measure was less than 0.07, indicating that the short scale had a similar relationship to the nomological network as the full scale.

### Appendix B References

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