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Profiles of middle school science teachers: Accounting for cognitive and motivational characteristics

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Abstract

Teachers play a critical role in successfully implementing science education reforms in the United States to provide high-quality science learning opportunities to all students. However, the differentiated ways in which teachers make decisions about their science teaching are not well understood. This study takes a person-centered approach by applying latent profile analysis to examine how cognitive (pedagogical content knowledge) and motivational (instructional goal orientations, self-efficacy beliefs, and reform values) characteristics combine to form science teacher profiles in middle school. Predictors of profile membership (bachelor's degree, school %FRL) and both teacher (science instructional practices) and student (science achievement, engagement, and self-efficacy) outcomes related to the teacher profiles were also examined. Five science teacher profiles were identified (severely discouraged but reform oriented, discouraged but reform oriented, conventional, confident and mastery oriented, and confident with multiple goal approaches) that represented unique configurations of cognitive and motivation characteristics. Additionally, findings showed that the teacher profiles were significantly related to three dimensions of science instructional practice including communication, discourse, and reasoning. Finally, the teacher profiles were significantly related to student science achievement and motivational outcomes. Implications for differentiated approaches to teacher professional learning and supports for science instruction are discussed.

KEYWORDS

latent profile analysis, pedagogical content knowledge, professional development, science education, teacher motivation and beliefs, teacher cognition

Supporting teachers' ability to serve as change agents in their school is critical for the successful implementation of ambitious science education reforms focused on improving science learning opportunities for all students (National Research Council (NRC), 2012; NGSS Lead States, 2013). Across the United States, teachers are asked to integrate scientific practices with disciplinary core ideas and cross-cutting concepts in their classrooms (NRC, 2012). Given the critical role that teachers play in implementing reformed approaches, it is important to better understand the differentiated ways teachers approach their profession. However, little is known about how science teachers vary in their characteristics, motivations, and values that underlie choices and enactments of science instruction, and in turn, their students' learning and achievement. Scholars have argued that similar to students, there are important variations in the ways teachers process, interpret, and adopt information to inform their practice (Bae, Hayes, O'Connor, Seitz, & DiStefano, 2016; Bae, Hayes, Seitz, O'Connor, & DiStefano, 2016; Day, Sammons, Stobart, Kingston, & Gu, 2007; van der Lans, van de Grift, & van Veen, 2017). Unfortunately, these differences among teachers are often overlooked in studies examining improvements in educational practices; "There are too many guides and "cookbooks" that indiscriminately propagate…dozens of techniques and strategies" without accounting for how teachers understand, choose, and adopt these strategies (De Florio, 2016, p. 1). Further, the variation in how teachers engage in their profession has important consequences for how students learn science, but few studies have examined the relationship between unique teacher profiles of such variable attributes and student outcomes.

This study aims to address these gaps in the literature by taking a person-centered approach to examine how malleable teacher characteristics, including their pedagogical content knowledge (PCK) and motivation (instructional goal orientations, self-efficacy beliefs, and pedagogical reform values) cluster into unique science teacher profiles. In addition, the relationships among these profiles and antecedents (e.g., bachelor's degree, school %FRL) and outcomes (science instructional practices and student outcomes) will be examined to illustrate the ways in which profiles of individual teacher characteristics relate to predictors, teachers' approaches to reform practices, and students' learning in science. We emphasize that our goal is not to categorize individual teachers in a deficit manner nor to assume teacher characteristics and/or profile membership cannot change over time. Rather, our study identifies meaningful differences in science teacher profiles along cognitive and motivational characteristics that will inform differentiated approaches to teacher professional development and supports for science instruction that appropriately target teachers' needs.

Our focus on teacher profiles in science is timely, given recent national science education reforms that present an integrated framework for K12 science education (NRC, 2012). The tenets of these new standards present significant shifts in how science is taught. Teachers will need to make cross-disciplinary connections (across earth, life, and physical sciences) and facilitate meaningful opportunities for students to learn disciplinary ideas through active engagement in scientific practices (NGSS Lead States, 2013). Shifting science instruction to align with these reform goals will likely require teachers to broaden their content knowledge and adapt their pedagogical approaches. Further, these reform-based shifts are likely to be met by a range of responses from classroom teachers, influenced by individual differences in their motivation (instructional goal orientations), sense of confidence in their science teaching ability (self-efficacy), and pedagogical reform values that may or may not align with these reform efforts. Finally, science is a unique context characterized by both opportunities related to recent reforms but also challenges regarding the lack of priority for science education in comparison to language arts and mathematics (Bae & DeBusk-Lane, 2018; Bae, DeBusk-Lane, Hayes, & Zhang, 2018; Hayes & Trexler, 2016). Taken together, this study will contribute to the existing literature by including a comprehensive set of cognitive and motivational characteristics to identify teacher profiles in middle school science and examining the relationship of these profiles with key antecedents and instructional as well as student outcomes.

1 | PERSON-CENTERED APPROACHES TO IDENTIFYING TEACHER PROFILES

Person-centered approaches categorize persons into distinguishable subgroups based on a set of shared characteristics (Marsh, Lüdtke, Trautwein, & Morin, 2009). Specifically, latent profile analysis (LPA) allows researchers to identify unique latent profiles that represent distinct configurations of observed variables of interest (Muthén & Muthén, 1998–2017; Pastor, Barron, Miller, & Davis, 2007). This approach can also be used to examine how teacher profiles are associated with specific predictors (e.g., teacher demographic characteristics) and instructional and student outcomes (Marsh et al., 2009). Recently, a small body of research examining teacher profiles has emerged, including profiles of instructional practice (Halpin & Kieffer, 2015), motivational profiles (in de Wal, den Brok, Hooijer, Martens, & van den Beemt, 2014; Perera, Calkins, & Part, 2019), profiles related to stress, coping, and job satisfaction (Herman, Hickmon-Rosa, & Reinke, 2018; Perera, Granziera, & McIlveen, 2018), and assessment profiles (Veldhuis & van den Heuvel-Panhuizen, 2014). Findings from these studies show that teachers do in fact cluster into unique subgroups characterized by different configurations of individual characteristics. In addition, findings show that teacher profiles are meaningfully related to professional engagement (e.g., Veldhuis & van den Heuvel-Panhuizen, 2014), assessment practices (e.g., Veldhuis & van den Heuvel-Panhuizen, 2014), and student outcomes (e.g., Halpin & Kieffer, 2015). For example, Halpin and Kieffer (2015) identified four unique profiles of middle school (Grades 6–8) English Language Arts teachers who were differentially associated with student outcomes including verbal achievement, engagement in school, and socioemotional development. In another example, secondary teacher motivation profiles (extremely autonomous, moderated motivated, highly autonomous, and externally regulated) were differentially associated with engagement in professional development activities (in de Wal et al., 2014).

2 | A FRAMEWORK TO ACCOUNT FOR TEACHERS' KNOWLEDGE, MOTIVATIONS, AND VALUES IN SCIENCE TEACHING

There is a large body of literature examining the relationship between teacher characteristics and their instructional practices. However, similar to the tradition of examining student cognition separately from motivation (Gregoire, 2003; Pintrich, Marx, & Boyle, 1993), the literature examining traditionally cognitive aspects of teacher practice (e.g., PCK) remain largely separate from the literature examining teachers' motivation (Keller, Neumann, & Fischer, 2017; Sorge, Keller, Neumann, & Möller, 2019). Scholars have called for the need to examine cognition and motivation together, arguing that motivational factors, such as an individual's goals, self-efficacy, and interest underlie the drive to activate and apply existing knowledge in practice (e.g., Gregoire, 2003; Pintrich et al., 1993; Sinatra, 2005; Van Veen, Sleegers, & Van de Ven, 2005). Teachers' individual differences along cognitive and motivational factors may also work together to influence classroom practice and students' learning in unique ways (Keller et al., 2017; Van Veen et al., 2005).

To this end, we draw from the Gregoire's (2003) Cognitive-Affective Model of Conceptual Change (CAMCC), which identifies various cognitive and motivational characteristics of teachers that, along with context, influence how teachers interpret and respond to reform messages in their science instruction. The focus of the CAMCC framework on the combined influence of cognitive and motivational characteristics that support or impede change in teachers' instructional approaches aligns well to the aim of this study to account for both types of characteristics in identifying profiles of science teachers. In this study, we included cognitive (PCK) and motivational or affective (goal orientations, self-efficacy, values) characteristics of teachers identified in the literature as related to science instruction and student outcomes.

Furthermore, we draw from Bronfenbrenner's (1979, 2001) ecological systems framework, which positions the individual (e.g., teacher) within a nested system of proximal (e.g., microsystem of the relationships and processes in a classroom) to distal (macrosystem of sociocultural norms, socioeconomic climates) systems that reciprocally interact with teachers' individual characteristics (Figure 1). For example, we account for school socioeconomic status (SES) as a contextual characteristic of teachers' work environment that may predict their membership in a specific profile based on a large body of literature demonstrating the effects of school SES on science teachers' morale and self-efficacy (e.g., Perera et al., 2018; Weiss, 1999), opportunities or constraints for implementing high-quality science instruction (e.g., Bae et al., 2018; Bae, Hayes, O'Connor, et al., 2016; Hayes & Trexler, 2016), and students' science engagement and achievement (e.g., Bae & Lai, 2019; Quinn & Cooc, 2015). Each of the teacher characteristics included in this study are reviewed next.

3 | SCIENCE PCK

Science teachers' PCK has been argued to contribute to high-quality science instruction and students' achievement in science (Berry, Friedrichsen, & Loughran, 2015; Gess-Newsome, 2013; Gess-Newsome et al., 2019). Originally proposed by Shulman (1987), PCK operationalizes knowledge of not only the subject matter (i.e., content knowledge) but also how to effectively translate that subject matter knowledge to students (i.e., pedagogical knowledge). There is growing evidence for the relationship between PCK and reformed teaching practice (Bayram-Jacobs et al., 2019; Kulgemeyer & Riese, 2018; Park, Jang, Chen, & Jung, 2011), although some

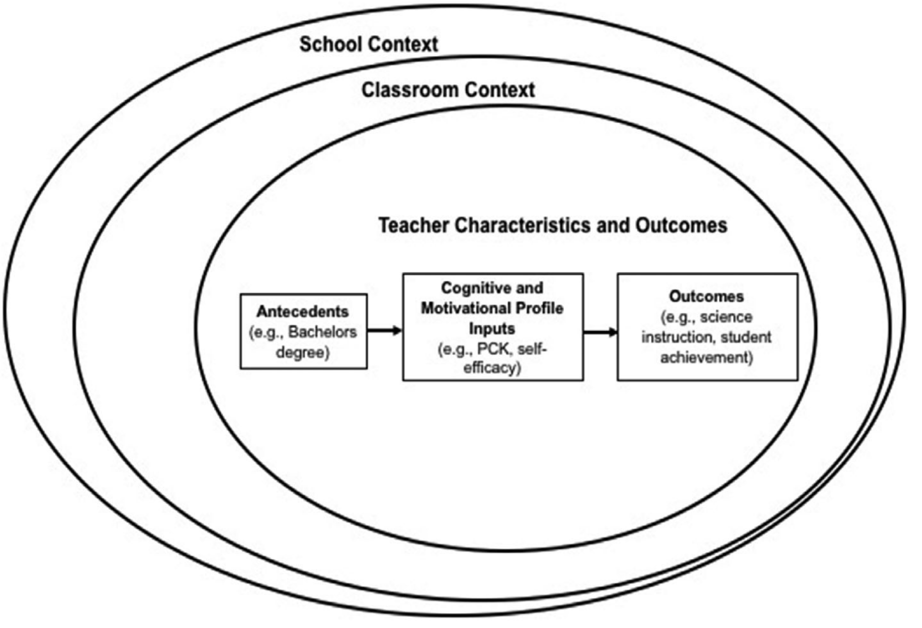

FIGURE 1 Framework of teachers' antecedent characteristics, cognitive and motivational profile inputs, and outcomes in context

studies did not demonstrate a statistically significant relationship (e.g., Cauet et al., 2015). Findings from a large number of studies demonstrate that high levels of PCK among math and science teachers are linked to instructional practices that support students' learning, such as activating students' prior understandings, anticipating students' questions and difficulties, and appropriately scaffolding students' sense-making around complex scientific phenomena (Ball, Thames, & Phelps, 2008; Bayram-Jacobs et al., 2019; Kunter et al., 2013; Kulgemeyer & Riese, 2018). For example, Kulgemeyer and Riese (2018) demonstrate that PCK mediates the relationship between content knowledge and teaching performance, showing specifically that content knowledge only had a positive influence on physics instruction if PCK increased as well.

Additionally, other studies demonstrate a relationship between teacher PCK and student attitude or motivation (Rohaan, Taconis, & Jochems, 2009). Finally, although a few studies have shown mixed or no relationship between PCK and student learning gains (Cauet, Liepertz, Borowski, & Fischer, 2015), others demonstrate such a relationship (Grosschedl, Welter, & Harms, 2014; Kanter & Konstantopoulos, 2010). In some cases, the relationship between PCK and student achievement has been found to be the greatest for underrepresented students, indicating a need for further research involving PCK as a key construct (Kanter & Konstantopoulos, 2010).

4 | SCIENCE TEACHER MOTIVATION

4.1 | Achievement goals

Achievement goal theory is a widely used motivation framework that proposes specific goals to explain individuals' behaviors. In this theory, two major types of goals that drive or motivate behaviors include mastery goals and performance goals (Ames, 1992; Pintrich, 2000;

Wormington & Linnenbrink-Garcia, 2017). Mastery goals are characterized as an orientation toward developing competence, whereas performance goals are characterized as an orientation toward demonstrating competence, often relative to others (Ames, 1992). The mastery and/or performance approaches that teachers enact in their science instruction send goal-related messages that student commonly adopt, and in turn, drive how students approach science learning (Kaplan, Middleton, Urdan, & Midgley, 2002; Meece, Anderman, & Anderman, 2006). For instance, teachers who promote mastery orientation are more likely to convey that effort and active sense-making is important in the science learning process, whereas teachers who promote performance orientation may use competitions and external benchmarks to drive students' learning in science classrooms. Mastery approaches to teaching are consistently associated with desirable learning behaviors (e.g., sustained engagement during challenging tasks), interest, and positive attitudes toward science learning (Britner & Pajares, 2006; Pajares, Britner, & Valiante, 2000), and science achievement outcomes (e.g., higher grades, deeper sense-making; Lee, Hayes, Seitz, DiStefano, & O'Connor, 2016; Meece et al., 2006). In contrast, findings regarding the influence of performance approaches are mixed, with some studies showing that goals focused on demonstrating competence (e.g., making the honors list) are associated with academic achievement, while other studies show that performance orientation is linked with maladaptive outcomes such as cheating (e.g., Ames, 1992; Meece et al., 2006).

4.2 | Self-efficacy

Based on the social cognitive theory of motivation, Bandura (1997) proposed that self-efficacy exerts a strong influence on the course of action a person decides to pursue, as well as their interpretations and reactions in a given situation. Teachers' self-efficacy, or their beliefs in their skills and abilities to be successful instructors within particular domains, is well established as a robust predictor of important teaching and learning outcomes (Zee & Koomen, 2016). For example, teachers' self-efficacy has been positively associated with implementation of reform-based science teaching and supportive classroom environments (Enochs, Scharmann, & Riggs, 1995; Lakshmanan, Heath, Perlmutter, & Elder, 2011; Perera et al., 2019), persistence in challenging instructional situations (Gibson & Dembo, 1984; Kulgemeyer & Riese, 2018; Tschannen-Moran & Hoy, 2001), and students' science achievement (Lumpe, Czerniak, Haney, & Beltyukova, 2012).

5 | SCIENCE TEACHERS' PEDAGOGICAL REFORM VALUES

Teacher values have long been considered a key component of the internal characteristics that shape teacher practice (Clarke & Hollingsworth, 2002). Here, we delineate between teacher beliefs and teacher values. As described earlier, beliefs are evaluative assumptions about how particular pedagogies will lead to particular outcomes usually informed by experiences (Bandura, 1997). A value, on the other hand, represents the inherent worth of a pedagogical principle (Armstrong & Muenjohn, 2008). Such values are often also quite stable and not subject to quick change (Luft, 2001). Alignment in teachers' pedagogical values has been shown to support reform-oriented instructional practice and to motivate instructional change (Hayes, Wheaton, & Tucker, 2019).

6 | ANTECEDENTS OF THE SCIENCE TEACHER PROFILES

Two antecedents of teacher profiles examined in this study include teachers' bachelor's degree and the percent of students in their schools that qualified for the Free or Reduced Lunch (FRL) program. Teachers' bachelor's degree, and specifically whether they majored in a natural science subject (e.g., Biology, Chemistry) or not (e.g., Education, Psychology), served as an indicator of teachers' preparation regarding their discipline-specific training. This decision was based on past research showing a positive link between teachers' undergraduate education and classroom quality as well as student achievement across domains (e.g., Kumar & Morris, 2005; Smith, Nelson, Trygstad, & Banilower, 2013). Additionally, school %FRL was selected as an important contextual variable, serving as a proxy for the socioeconomic status of the school that may predict the likelihood of teacher profile membership. Past research has shown that teachers' preparation and instructional practices are strongly linked to the institutional structures associated with school socioeconomic status, such as resources available for science, opportunities for professional development, accountability pressures, and school climate (Bae, Hayes, O'Connor, et al., 2016; Bae, Hayes, Seitz, et al., 2016; Hayes & Trexler, 2016). For example, it is well established that science teachers in low SES schools tend to have lower quality preparation (and in turn, lower PCK), which coupled with the challenges present in their instructional contexts, can be linked to low motivation and self-efficacy in science teaching (Goldhaber, Lavery, & Theobald, 2015; Lankford, Loeb, & Wyckoff, 2002; Lee & Mamerow, 2019).

7 | OUTCOMES OF THE SCIENCE TEACHER PROFILES: SCIENCE INSTRUCTIONAL PRACTICES AND STUDENT ENGAGEMENT, SELF-EFFICACY, AND ACHIEVEMENT

7.1 | Science instructional practices

How teachers approach science in their classrooms has a strong relationship with student learning. Multiple dimensions of instructional practices have been found to support students' understanding of science phenomena, motivation to learn science, and increased science test scores (e.g., Geier et al., 2008; Hayes, Lee, DiStefano, O'Connor, & Seitz, 2016; McNeill & Krajcik, 2008; Munch, 2007; NRC, 2012). The first, empirical investigation, consists of the opportunity for students to observe phenomena, ask questions, plan experiments, and collect and analyze data. In this area, research has shown that the level of student learning may be dependent on the degree of student involvement and cognitive demand embedded in the learning tasks (Hayes et al., 2016; NRC, 2012; Tekkumru Kisa, Stein, & Schunn, 2015; Zimmerman, 2007). The second, modeling and explanation, focuses on students having the opportunity to generate and use models of scientific phenomenon, produce evidence in support of explanations, and critique scientific ideas. Engaging in such experiences supports students' understanding of the norms and practices by which scientists make decisions, dispute findings, and link claims to evidence (Jiménez-Aleixandre & Erduran, 2007; Schwarz et al., 2009). The third consists of science discourse and communication. Because scientific knowledge is socially constructed, classroom instruction should provide students with various opportunities for sense-making through discourse with their peers, as well as opportunities to communicate scientific evidence (Lemke, 2001; Norris, Philips, & Osborne, 2008). Finally, more traditional instructional approaches (e.g., direct instruction, reading from textbooks) and incorporating student' prior knowledge may be important for supporting sense-making, in balance with more student-directed and engaged learning opportunities (Driver, Newton, & Osborne, 2000; Zimmerman, 2007).

Rather than advocating for the sole use of any given instructional practice, recent research has pointed to the need to balance pedagogical practices to provide the greatest support for student sense-making of science ideas and natural phenomena (Hmelo-Silver, Duncan, & Chinn, 2007; Zimmerman, 2007). Research has demonstrated a relationship between teacher characteristics and particular instructional practices. For example, studies have also shown that reform-aligned beliefs and values have a relationship with enactment of reforms in the classroom, such as the incorporation of more inquiry-based pedagogies (Hayes et al., 2019; Luft, 2001; Munck, 2007; Supovitz & Turner, 2000). Additionally, studies show that teachers self-efficacy beliefs and understanding of science content support inquiry practices (Minner, Levy, & Century, 2009; Supovitz & Turner, 2000).

7.2 | Students' engagement, self-efficacy, and science achievement

For student outcomes, we included motivational (engagement, self-efficacy) and cognitive (science achievement) aspects of students' science learning. Student engagement is a multi-dimensional construct that encompassed how students act (behavior), feel (affect), and think (cognitive) (Fredricks, Blumenfeld, & Paris, 2004; Wang, Fredricks, Ye, Hofkens, & Linn, 2016) and was included as it is a key driver of students' science learning behaviors and achievement outcomes such as meaningfully participating in peer-to-peer argumentation, interest and persistence in advanced science courses, and higher standardized test scores (Lee et al., 2016; Wang & Holcombe, 2010). Students' science self-efficacy, or the beliefs students hold about their abilities to be successful in science, was also examined in relation to the teacher profiles. Self-efficacy has been established as a central motivation construct that predicts a host of positive outcomes including science content understanding, perseverance on challenging science tasks, and continuation in science-related majors and careers (Britner & Pajares, 2006; Lee et al., 2016; van Aalderen-Smeets, Walma van der Molen, & Xenidou-Dervou, 2019). Finally, we examined students' science achievement using proximal, grade-specific assessments of content knowledge (Ruiz-Primo, Shavelson, Hamilton, & Klein, 2002), representing a more traditional, cognitive learning outcome.

7.3 | Present study

In the present study, we first aimed to identify unique middle school science teacher profiles that accounted for key teacher cognitive and motivational characteristics that have important implications for instructional approaches and student learning outcomes. To date, the majority of teacher profile studies have focused on classroom practices (e.g, Halpin & Kieffer, 2015; Veldhuis & van den Heuvel-Panhuizen, 2014), affective characteristics including motivational dispositions (intrinsic, extrinsic, self-efficacy beliefs; in de Wal et al., 2014; Herman et al., 2018; Perera et al., 2019), and personality traits (Perera et al., 2018) as they relate to professional learning, satisfaction in the profession, and student outcomes. We contribute to the existing literature by accounting for both cognitive and motivational characteristics in teacher profiles, including PCK, motivational approaches to instruction (mastery and performance goal orientations), self-efficacy in science teaching, and pedagogical values related to science reform efforts (e.g., valuing of equitable opportunities for student discourse, phenomena-based exploration). Identifying unique teacher profiles can inform appropriately differentiated approaches to professional learning that takes into account how teachers understand and implement principles of science reform in their instruction.

Secondly, we examined how demographic variables, including bachelor's degree (science vs. non-science subject) and school %FRL predicted the likelihood of profile membership. Finally, the relationships between each science teacher profile and science instructional practices, as well as student learning outcomes (engagement, self-efficacy, science achievement), were examined.

8 | RESEARCH QUESTIONS AND PREDICTIONS

1. What middle school science teacher profiles emerge from the set of malleable characteristics including science PCK and motivational beliefs (achievement goal orientations, self-efficacy, and pedagogical values aligned to reformed science teaching)?
2. How do teacher qualification (bachelor' degree) and the school socioeconomic status (%FRL) predict science teacher profile membership?
3. How do the science teacher profiles relate to instructional practices in middle school classrooms?
4. How do the science teacher profiles relate to middle school students' engagement, self-efficacy, and achievement in science?

Based on the existing literature on teacher cognition and motivation, and teacher profiles, we expected to identify four to five unique profiles. Also based on past studies of motivation profiles, we expected profiles to emerge characterized in the following ways: first, there will likely be a profile characterized by high mastery approaches to instruction and high self-efficacy coupled with low performance approaches. This profile is comparable to in de Wal et al.'s (2014) highly and an extremely autonomous teacher, and similar to the highly efficacious teacher in Perera et al.'s (2019) study. The second is a low mastery and low self-efficacy coupled with high-performance approaches to instruction (e.g., externally regulated teachers, in de Wal et al., 2014; highly inefficacious teachers, Herman et al., 2018; Perera et al., 2019). Finally, we expected two profiles with varying levels of motivation, which represent endorsement of multiple goal approaches and moderate self-efficacy (e.g., moderately motivated teachers, in de Wal et al., 2014; moderately confident teachers, Perera et al., 2019). We also expected to identify profiles that align with traditional notions of discouraged teaching (e.g., low PCK, lack of self-efficacy) and more motivated teaching (e.g., high PCK, mastery approach to teaching) and also additional profiles that present unique teacher profiles, such as teachers with low PCK but high pedagogical value alignment and mastery approaches to instruction, and teachers with high content knowledge who have more traditional values about how to best address students' learning needs (e.g., Borko, Liston, & Whitcomb, 2007; Nathan & Petrosino, 2003).

In regard to the antecedents of science teacher profiles, we expected that a bachelor' degree in science would predict a higher likelihood of membership in the profiles characterized by higher PCK. We expected the school %FRL would predict membership into profiles with lower PCK, lower mastery orientation toward instruction, lower self-efficacy, and less alignment with reform-based pedagogical values. Similarly, in regard to the outcomes, we expected profiles characterized by higher scores on the cognitive (PCK) and motivation indicators (e.g., mastery goals, self-efficacy, pedagogical reform values) to be associated with greater implementation of reform-based instructional practices and student outcomes.

9 | METHODS

9.1 | Sample and procedures

A total of 101 middle school teachers in Grades 6 ($n = 35$), 7 ($n = 33$), and 8 ($n = 33$) across seven urban school districts in the western region of the United States participated in the study. This sample size is adequate based on the recommendations in the literature (Lubke & Muthén, 2007; Masyn, 2013; Tein, Coxe, & Cham, 2013), as well as empirical evidence from past person-centered studies of teachers using similar sample sizes (e.g., Herman et al., 2018). Teachers were recruited to participate in this study as part of a larger science education project. The teacher sample included male (31.7%) and female (68.3%) teachers, with an average of 12.89 ($SD = 7.69$) years of teaching, who identified as Asian/Pacific Islander (18.9%), African American/Black (2.6%), Hispanic or Latinx (7.6%), Caucasian/White (63.3%), and Two or more Races (7.6%). The teachers served in schools where 53.16% of the students qualified for FRL and 17.92% of students were identified as English Language Learners. Student data from participating teachers included in this study were their grade-specific science achievement scores. The students' samples in this study ($n = 1848$) were between the ages of 11 and 13 years and were identified as male (46.4%) or female (53.6%), Caucasian/White (25.9%), Hispanic or Latinx (45.3%), Asian (20.8%), African American/Black (6.2%), and Other (1.7%). Approval from the university's institutional review board was obtained prior to data collection. Paper-and-pencil self-report questionnaires and PCK assessments were collected via mail. All survey items were rated on a 5-point Likert scale ranging from 1 (*Not true at all*) to 5 (*Very true*) and composite scores were computed. The science PCK score represents the percentage of total correct responses on a multiple choice assessment. All teacher and student survey data were collected near the end of the academic year.

9.2 | Teacher measures

9.2.1 | Science instruction goal orientation and self-efficacy

Items from the Patterns of Adaptive Learning Scales (PALS; Midgley et al., 2000) were used to ask teachers about their science teaching goal orientations, including mastery approaches (4 items, e.g., "I make special effort to recognize students' individual progress, even if they are below grade level," $\alpha = .81$) and performance approaches (4 items, e.g., "I display the work of the highest achieving students as an example," $\alpha = .87$, Midgley et al., 2000). Items from PALS (Midgley et al., 2000) were used to assess teachers' self-efficacy in science (7 items, e.g., "I am good at helping the students in my science class make significant improvements," $\alpha = .92$, Midgley et al., 2000). We also found evidence for adequate reliability of the mastery, performance approach, and self-efficacy subscale scores ($\alpha = .73$, .77, and .81, respectively).

9.2.2 | Science PCK assessment

Science PCK was measured using multiple-choice science assessments that corresponded to the teachers' grade-level content (plate tectonics for the sixth grade, populations and ecosystems for the seventh grade, and force and motion/properties of, and changes in matter for the eighth grade) developed by Horizon Research Institute (2013). These PCK assessments were developed to measure teachers' science content knowledge, knowledge for diagnosing students' thinking, and application of content knowledge to instruction (e.g., "A student asks his teacher how erosion should be addressed when discussing the effects of plate tectonics. Which one of the following would be a correct teacher response to this question?"). Science PCK scores represent the total percentage correct and scores from the present sample demonstrated high reliability (α = .72–83).

9.2.3 | Science pedagogical reform values (adapted from Aron, Aron, & Smollan, 1992; Schultz, 2002)

The pedagogical reform value alignment scale measures the degree of alignment between a given set of reform-based pedagogical principles and the teachers' own pedagogical values. In this scale, teachers consider four statements, each representing a pedagogical principle (e.g., The role of teachers should shift from being the primary source of knowledge to being a facilitator of learning). This requires that students consistently engage in developing explanations through investigating scientific phenomena). They are then presented with five pairs of overlapping circles, from completely 1 (*separated*) to 5 (*completely overlapped*). Ratings of the items demonstrated high reliability (α = .92, Hayes et al., 2019; α = .88 in the present sample).

9.2.4 | Science instructional practices survey (SIPS; Hayes et al., 2016)

Science instructional practices survey (SIPS) was developed to assess a comprehensive set of science instructional practices that include the Next Generation Science Standards science and engineering practices (NGSS Lead States, 2013). Teachers were asked to rate the extent to which they or their students engaged in each area from 1 (*Never*) to 5 (*Everyday*). The SIPS consists of a total of 31 items to measure science instruction along eight dimensions including communicating science, scientific discourse, investigation, data collection and analysis, explanation and argumentation, modeling, traditional instruction, and prior knowledge (Hayes et al., 2016). Evidence for the factor structure, internal reliability, and validity of the scores from the SIPS subscales are presented in a prior study (Hayes et al., 2016). Scores from the present study also demonstrated moderate to high reliability (α = .74–.89 across the eight dimensions).

9.3 | Student measures

The items from existing student self-efficacy and engagement questionnaires were adapted to examine students' self-efficacy and engagement in the context of their science classrooms (e.g., Osborne, Simon, & Collins, 2003). The reliability (test–retest, factor structure, internal consistency) and validity of scores from the student self-efficacy and engagement subscales among two independent samples of middle school students was found in a previous study (Lee et al., 2016). The published science concept inventories were adapted by science faculty who were part of a larger science education project (Lee et al., 2016).

9.4 | Student self-efficacy survey

The student self-efficacy (e.g., "Even if the science class work is hard, I can do it", 5 items) subscale was drawn from PALS (Midgley et al., 2000). Past studies showed that Cronbach's α for the self-efficacy scale ratings ranged from .74 to .89 (Lee et al., 2016; Midgley et al., 2000; Pajares et al., 2000).

9.5 | Student engagement survey

The engagement items were adapted from existing measures (Fredricks et al., 2004) to assess three dimensions of engagement: behavioral (5 items, e.g., "I follow the rules in my science class"), affective (5 items, e.g., "I feel excited by the learning activities in my science class"), and cognitive (e.g., "In science class, I ask questions and offer suggestions", 7 items) engagement. Cronbach's α values of the ratings were .76, .83, and .77 for the behavioral, affective, and cognitive subscales, respectively (Lee et al., 2016).

9.6 | Science achievement

Students' science achievement was measured using grade-specific concept inventories (CI). Grade 6 earth science CI (30 items) was adapted from a published assessment tool (α = .76; Libarkin, Kurdziel, & Anderson, 2007). Life grade 7 life science CI (18 items) was adapted from the *Conceptual Inventory of Natural Selection* (Anderson, Fisher, & Norman, 2002; α = .81). Grade 8 physical science CI (25 items) was developed and validated by the Physics Underpinnings Action Research Team from Arizona State University (Evans et al., 2003; α = .83). The total percentage correction on the science CI was used in this study.

9.7 | Analyses

9.7.1 | LPA of middle school science teachers

Using *M*Plus*8* (Muthén & Muthén, 1998–2017), the final LPA was estimated with 6,000 random starting values, 1,000 initial stage iterations, and 200 final-stage optimizations (Masyn, 2013). During the enumeration phase, each LPA was estimated allowing the means to be free, yet constraining the between profile indicator variances equal. Raw *z*-scores were used as indicator items. We used both statistical and theoretical justifications (Marsh et al., 2009; Nylund, Asparouhov, & Muthén, 2007). Statistically, models were inspected on their fit based on minimum values of Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), whereby smaller values indicate parsimony (Collins & Lanza, 2013; Geiser, 2013). Additionally, we assessed the Vuong Lo–Mendell–Rubin (VLMR) *p* values in instances of nonsignificances, which suggest taht the k – 1 model is preferable (Geiser, 2013). Lastly, the extent to which the profiles were substantively distinguishable was examined based on model entropy and the classification probabilities (Lubke & Muthén, 2007; Reinecke, 2006). Finally, a theoretical approach was taken to best determine the most interpretable and distinguishable number of profiles.

9.8 | Predictors and outcomes of profile membership

We then examined the predictive value of whether or not a teacher held a bachelor's degree and school %FRL as well as how the profiles exhibited differences across the eight science instructional practices and student self-efficacy, engagement, and science achievement outcomes. Each predictor (bachelor's degree, school %FRL) was evaluated using Mplus' R3STEP function, which applies a multinomial logistic regression while accounting for classification error (Bakk & Vermunt, 2016). In doing so, $k - 1$ regression coefficients were generated in relation to a reference profile that allowed us to then transform the coefficients into log odds for better interpretability. The mean of each outcome was assessed by profile using the BCH function in M*Plus*. The equality of each outcome mean between profiles was assessed using a Wald chi-square analysis (Asparouhov & Muthén, 2014).

10 | RESULTS

10.1 | Science teacher five-profile solution

Fit indices for two to seven latent profile solutions are presented in Table 1. The information criterion values (e.g., AIC, BIC) continued improving (i.e., decreasing in value) with the addition of latent profiles. There was a slight increase in the BIC value for the five-profile solutions (change in BIC = 4.95), indicating that a profile solution may best fit the data. However, we examined whether the four- and five-profile solutions showed distinguishable profiles based on theory and previous research (Marsh et al., 2009). We noticed that two substantively distinguishable profiles in the five-profile solution were aggregated into a less interpretable profile when reduced to the four-profile solution. Specifically, the profiles from the four-profile

TABLE 1 Latent profile analysis fit statistics for 2 to 7 class solutions

N_{Classes}	Log$L$	AIC	Δ AIC	BIC	Δ BIC	VLMR-LRT	p value	Entropy
2	−529.723	1,091.446	—	1,133.288	—	67.832	.0051	.762
3	−496.103	1,036.205	−55.241	1,093.738	−39.55	67.241	.0005	.946
4	−482.222	1,020.443	−15.762	1,093.667	−0.071	27.762	.1207	.870
5	**−470.624**	**1,009.248**	−11.195	**1,098.612**	4.945	**23.195**	**.5373**	**.879**
6	449.311	978.622	−30.626	1,083.227	−15.385	42.626	.0829	.952
7	−344.981	781.963	−196.659	902.259	−180.968	162.656	.5111	.969

Note: Minimal BIC indicates best relative fit. Significant VLMR denotes an improvement in fit given the additional class. Bold values represent the final model selected.

Abbreviations: AIC, Akaike Information Criterion; aBIC, sample size adjusted Bayesian Information Criterion; BIC, Bayesian Information Criterion; logL, log likelihood; VLMR-LRT, Vuong Lo–Mendell–Rubin likelihood ratio test.

solution were replicated in the five-profile solution; however, a new "*Conventional*" profile was identified that accounted for approximately 20% of the teachers in the sample, and theoretically aligned with the literature that indicates a subgroup of teachers with high content knowledge and more traditional values and approaches to science teaching (e.g., Borko et al., 2007; Nathan & Petrosino, 2003). Additionally, the entropy value (.88) as well as the classification probabilities (ranging from .87 to .97) indicated adequate classification accuracy. Thus, based on the fit indices, findings from the existing literature, and theory, the five-profile solution was selected as the most optimal. The five profiles and their labels are presented in Figure 2. The means of all profiles inputs are presented in Table 2. The results for each of these five profiles are described in more detail later.

10.2 | Profile 1: Severely discouraged but reform oriented

The *Severely discouraged but reform-oriented science teacher* profile represented the smallest profile ($n = 10$), which was characterized by the highest reform-aligned values (approximately .5 *SD* above the mean), but also the lowest mastery approaches to science instruction and the lowest self-efficacy in science teaching (approximately 1–2 *SD* below the mean). Teachers in this profile also demonstrated low performance approaches to science instruction (approximately 1 *SD* below the mean) and slightly below average PCK. Thus, the *Severely discouraged but reform-oriented science teacher* profile represents middle school science teachers who strongly endorse science education reforms focused on more integrated and phenomena-based student-centered activities that provide ongoing opportunities for students to participate in disciplinary practices. However, interestingly, these same teachers are characterized by using

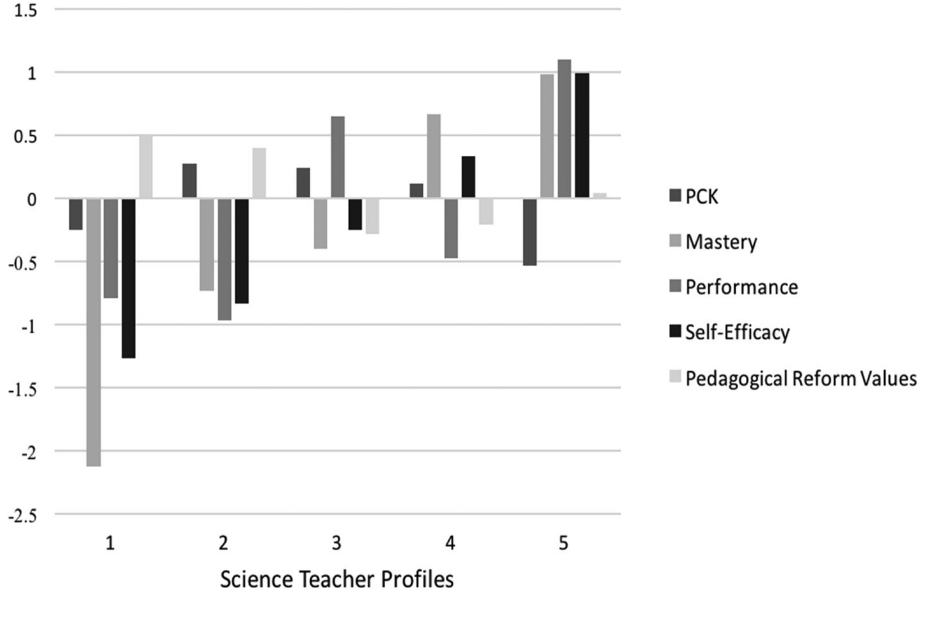

FIGURE 2 Science teacher 5-profile solution: (1) *Severely discouraged but reform oriented* ($n = 10$), (2) *Discouraged but reform oriented* ($n = 15$), (3) *Conventional* ($n = 21$), (4) *Confident and mastery-oriented* ($n = 35$), and (5) *Confident with multiple goal approaches* ($n = 20$)

TABLE 2 Descriptive statistics of all predictor and input variables by science teacher profile

Variable	Severely discouraged but reform-oriented	Discouraged but reform-oriented	Conventional	Confident and mastery oriented	Confident with multiple goal orientations
	M	*M*	*M*	*M*	*M*
n	10	15	21	35	20
Pedagogical content knowledge	−.250	.272	.239	.112	−.532
Mastery approach	−2.130	−.730	−.398	.671	.988
Performance approach	−.788	−.966	.650	−.472	1.105
Self-efficacy	−1.265	−.831	−.249	.330	.989
Pedagogical reform values	.502	.399	−2.81	−.205	.044

Abbreviation: *M*, standardized mean ratings for profile inputs.

instructional approaches that do not promote mastery or performance approaches to science instruction, low self-efficacy in science teaching, and slightly below average PCK. Thus, while teachers in this profile seem to hold values that are in line with reformed science teaching, they may also be lacking the confidence, motivation, and PCK to enact reformed science teaching.

10.3 | Profiles 2: Discouraged but reform-oriented

The *Discouraged but reform-oriented science teacher* profile represented the second smallest profile ($n = 15$), which was characterized by above average reform-aligned beliefs (approximately .5 *SD* above the mean) and PCK (approximately .25 *SD* above the mean). Similar to the *Severely discouraged but reform-oriented* profile, this profile was characterized by below average self-efficacy in science teaching, and below average mastery and performance approaches to instruction (approximately 1 *SD* below the mean across all three of these indicators). However, these teachers were characterized as *Discouraged* because they reported moderately low motivation and self-efficacy in comparison to the *Severely discouraged* profile. An additional difference was that teachers in this profile were characterized by above average PCK, whereas the *Severely Discouraged* profile was characterized by below average PCK.

10.4 | Profile 3: Conventional

The *Conventional science teacher* represented the second largest profile ($n = 21$), which was characterized by the lowest reform-aligned values (approximately .5 *SD* below the mean), as well as below average mastery approaches to science instruction and self-efficacy beliefs (approximately .25 to .50 *SD* below the mean). However, these teachers had above average PCK (approximately .25 *SD* above the mean) and high performance approaches to science instruction (approximately .25 *SD* above the mean). Thus, this profile was labeled “conventional” to represent teachers with strong PCK, but whose beliefs and values are not aligned with reformed science teaching, and who endorse performance-based (e.g., using external rewards such as grades or external criteria such as standards-based assessments to motivate students' learning behaviors) over mastery-based approaches in their science instruction.

10.5 | Profile 4: Confident and mastery-oriented

The *Confident and mastery-oriented* profile was the largest in size (n = 35), characterized by above average mastery approaches to instruction and self-efficacy in science teaching (approximately .5 *SD* above the mean). On the other hand, the teachers in this profile are also characterized by average PCK, slightly below average reform beliefs, and low performance approaches to science instruction (approximately .5 *SD* below the mean). Thus, science teachers in this profile endorse high motivational approaches commonly associated with positive instructional and learning outcomes, but may not necessarily hold domain-specific expertise or have internalized science-specific reform values.

10.6 | Profile 5: Confident with multiple goal approaches

Finally, the *Confident with multiple goal approaches* profile represented the third largest profile (n = 20), characterized by the highest self-efficacy beliefs, and the highest mastery and performance approaches to science instruction (approximately 1 *SD* above the mean across all three of these indicators), average reform values, but also the lowest PCK (approximately .5 *SD* below the mean). These teachers are characterized by high confidence in their science teaching, and endorsement of various motivational approaches that include both an emphasis on effort and improvement (i.e., mastery approaches) as well as external criteria and competition (e.g., performance approaches). However, similar to the *Confidently mastery-oriented* profile, teachers in this profile may not have deeply internalized science-specific reform values, and also have lower science PCK indicating lack of disciplinary-specific expertise.

10.7 | Predictors and outcomes of teacher profile membership

10.7.1 | Predictors: Bachelor's degree and school %FRL

In terms of the predictors, results showed that neither teacher's bachelor degree nor school % FRL significantly predicted teacher profile membership (Table 3). The correlations among all observed teacher variables are presented in Appendix A.

10.7.2 | Teacher outcomes: Science instructional practices

The means of the eight dimensions of science instructional practices and student outcomes (student engagement, self-efficacy, and achievement in science) and a summary of the significant Wald chi-squared test differences between teacher profiles for each are presented in Table 4.

The *Conventional* profile (M = 3.40) was significantly higher compared with the *Confident and mastery-oriented* profile (M = 3.02; |2 = 6.15, p = .01, d = 0.72) on the communication dimension. The *Confident with multiple goal orientations profile* (M = 3.30) was significantly

TABLE 3 Multinomial logistic regressions of the predictors on teacher profile membership

Predictor	Profile 1 vs. 5			Profile 2 vs. 5			Profile 3 vs. 5			Profile 4 vs. 5			Profile 1 vs. 4		
	Coef.	SE	OR	Coef.	SE	OR	Coef.	SE	OR	Coef.	SE	OR	Coef.	SE	OR
Sch %FRL	−.016	.026	0.984	−.027	.019	0.973	−.002	.020	0.998	−.017	.020	0.983	−.001	.025	0.999
BA degree	1.157	1.296	3.180	−.756	.865	0.470	−.227	.784	0.797	−1.138	.784	0.320	−2.295	1.240	0.101
	Profile 2 vs. 4			Profile 3 vs. 4			Profile 1 vs. 3			Profile 2 vs. 3			Profile 1 vs. 2		
	Coef.	SE	OR	Coef.	SE	OR	Coef.	SE	OR	Coef.	SE	OR	Coef.	SE	OR
Sch %FRL	.010	.017	1.010	−.015	.018	0.985	.014	.025	1.014	.025	.019	1.025	−.011	.025	0.989
BA degree	−.381	.790	0.683	−.911	.741	0.402	−1.384	1.265	0.251	.530	.844	1.699	−1.913	1.282	0.148

Note: BA degree: 0, non-science major; 1, science major. The coefficient/OR represents the effect of the predictor on the likelihood of membership into the first listed profile relative to the second listed profile. Profile 1: Severely discouraged but reform-oriented; Profile 2: Discouraged but reform-oriented; Profile 3: Conventional; Profile 4: Confident and mastery oriented; Profile 5: Confident with multiple goal orientations.

Abbreviations: *SE*, standard error of the coefficient; OR, odds ratio; Schl %FRL: percentage of students in the school that qualify for Free and Reduced Lunch.

TABLE 4 Associations between teacher profile membership and science instructional practice

	Severely discouraged but reform-oriented	Discouraged but reform-oriented	Conventional	Confident and mastery-oriented	Confident with multiple goal orientations	Summary of significant differences
	M [CI]	*M* [CI]	*M* [CI]	*M* [CI]	*M* [CI]	
SIPS_Com	3.26	3.26	3.40	3.02	3.30	3 > 4; 4 < 5
SIPS_Dis	4.09	4.21	3.89	3.81	4.14	2 > 4
SIPS_Inv	3.05	3.19	3.12	3.02	3.02	—
SIPS_Inv2	3.58	3.49	3.46	3.39	3.40	—
SIPS_Mod	2.81	2.93	2.90	2.80	2.99	—
SIPS_Prior	3.99	4.05	3.90	3.89	4.20	—
SIPS_Reasoning	3.45	3.66	3.27	3.15	3.59	2 > 4; 4 < 5
SIPS_Trad	3.35	3.37	3.43	3.38	3.34	—
Stud_Engage	3.60	3.49	3.50	3.62	3.45	4 > 5
Stud_Self-efficacy	3.89	3.83	3.80	3.95	3.78	4 > 5
Stud_SciAch	39.77	47.97	42.41	42.37	37.89	2 > 5

Note: All differences presented are $p < .05$.
Abbreviations: *M*, mean; CI, 95% confidence interval.

higher on the communication dimension compared with the *Confident and mastery* oriented profile (M = 3.02; |2 = 5.07, p = .02, d = 0.66). The *Discouraged but reform-oriented profile* (M = 4.21) was significantly higher compared with the *Confident and mastery-oriented* profile (M = 3.81; |2 = 5.16, p = .02, d = 0.68) on the discussion dimension. Finally, the *Discouraged but reform-oriented profile* (M = 3.66) was significantly higher compared with the *Confident and mastery oriented* profile (M = 3.15; |2 = 5.52, p = .02, d = 0.73), and the *Confident with multiple goal orientations* profile (M = 3.59) was also higher compared with the *Confident and mastery oriented profile* (|2 = 5.31, p = .02, d = 0.70) on the reasoning dimension. All of the other differences were not statistically significant.

Taken together, the patterns across the significant Wald chi-squared tests showed that the *Discouraged but reform-oriented* teacher profile is associated with higher science instructional practices in the discussion and reasoning dimensions compared with the *Confident and mastery-oriented* teacher profile. The *Confident with multiple goal orientation* teacher profile was associated with higher science instructional practices in the communication and reasoning dimensions compared with the *Confident with mastery goal orientation* teacher profile. Finally, the *Conventional* teacher profile was associated with higher instructional practices in the communication dimension compared with the *Confident and mastery-oriented* teacher profile.

10.7.3 | Student outcomes: Student engagement, self-efficacy, and science achievement

In terms of the relationship between science teacher profiles and student outcomes, the results showed that students of the *Confident and mastery-oriented* teacher profile had significantly higher science engagement (|2 = 2.15, p = .03, d = 0.66) and higher science self-efficacy (|2 = 4.39, p = .04, d = 0.65) compared with the *Confident with multiple goal approaches* teacher profile. Additionally, students of the *Discouraged reform-oriented* teacher profile had significantly higher science achievement (|2 = 5.57, p = .02, d = 0.81) compared with the *Confident with multiple goal approaches* teacher profile. All of the other student outcome differences between teacher profiles were not statistically significant. Overall, our results suggest that the teacher profile associated with higher motivational approaches and self-efficacy (*Confident and mastery-oriented*) are significantly associated with students' engagement and self-efficacy in science, whereas the teacher profile associated with higher PCK and pedagogical reform values (*Discouraged reform-oriented*) is significantly associated with higher science achievement. However, given the small number of statistically significant Wald chi-squared tests differences, these patterns should be interpreted cautiously.

10.7.4 | Discussion of findings and implications for practice

The objective of this study was to identify science teacher profiles, which include a comprehensive set of both cognitive (PCK) and motivational (goal orientations, self-efficacy, and pedagogical reform values) characteristics established in the literature as robust predictors of science instruction and student learning outcomes. By taking a person-centered approach, we contribute to the literature by demonstrating how cognitive and motivational characteristics cluster within teachers at different levels. This approach differs from variable-centered approaches by testing the assumption that teachers uniformly possess the same level of knowledge, drives, and values across different cognitive and motivational factors. Specifically, in line with our predictions, five unique science teacher profiles were identified. Additionally, we examined the relationship between the profiles and both instructional and student learning outcomes. In contrast to variable-centered approaches, person-centered approaches provide a more nuanced look at how profiles, representing unique clusters of factors related to science teachers' cognition, motivation, and values, relate to their teaching practices and students' science achievement. Results showed evidence of significant differences between profiles for three dimensions of instructional practice (i.e., communication, discussion, and/or reasoning) and for students' engagement, self-efficacy, and achievement in science.

10.8 | Science teacher profiles indicate multiple goal approaches

As expected, the science teacher profiles represented a range of extremely low to high levels of motivational approaches to instruction and self-efficacy in science teaching. Of the three science teacher profiles characterized by high endorsement of one or more of the achievement goal orientations, we see unique configurations of motivation dispositions including teachers who endorse performance approaches to their instruction (e.g., use external benchmarks or competitions to motivate students' learning; *Conventional*), teachers who endorse mastery approaches to their instruction (e.g., focus on students' progress and improvements; *Confident and mastery-oriented*), and teachers who endorse multiple or both mastery and performance approaches in their instruction (*Confident with multiple goal approaches*). Additionally, consistent with the existing literature and our predictions, mastery approaches to instruction and self-efficacy were uniformly endorsed across the profiles (i.e., within each profile, teachers reported mastery and self-efficacy that were both below, at, or above the mean). Thus, as established in past work, self-efficacy, or a belief in their ability to be successful in science teaching, seems to go hand in hand with mastery approaches to instruction (Meece et al., 2006; Perera et al., 2019). The identification of two science teacher profiles (*Confident and mastery-oriented*, *Confident with multiple goal approaches*) that are characterized by high mastery orientations and science efficacy in their science instruction is encouraging, particularly as these represented about half of the teachers in this study's sample. These teachers have positive self-referent judgments about their personal teaching abilities on science-specific instructional tasks, such as implementing routines, prompting students' interest in science topics, and addressing multiple student learning needs (Perera et al., 2019). Teachers in these profiles are also more likely to create goal structures in their science classrooms through various instructional and assessment strategies that underscore deep understanding of disciplinary ideas and skill development (in de Wal et al., 2014; Meece et al., 2006).

Additionally, although motivation theory traditionally points to mastery approaches and high self-efficacy as important for supporting quality science instruction and student learning, more recent work that applied person-centered approaches to examine profiles of achievement goals indicate that endorsing multiple, or both mastery and performance goals simultaneously are associated with positive outcomes above and beyond a single goal (Bae & DeBusk-Lane, 2018; Wormington & Linnenbrink-Garcia, 2017). Our findings indicate that one of the teacher profiles (*Confident with multiple goal approaches*) align with the multiple goal perspective; that is, teachers who seem to simultaneously endorse mastery and performance approaches to science instruction. When considering the range of individual and situationally relevant needs students bring to the classroom, as well as the high stakes accountability policies and structures that often dictate instructional approaches, it is possible that performance-based approaches, such as having students compete in groups and stressing the importance of receiving good grades or scores, may be appropriate for engaging students who would otherwise lose interest and/or to familiarize students with the performance-based and competitive nature of pursuing science-related fields.

10.9 | Discouraged science teacher profiles manifest in at least two distinct ways

The other two teacher profiles characterized by low motivation and self-efficacy (*Severely discouraged with reform values, Discouraged with reform values*) represent profiles with some of the more extreme indicators (approximately 1 to 2 *SD* below the mean). These profiles include science teachers who hold negative beliefs about their ability to be successful in science teaching. Additionally, teachers in the *Severely discouraged with reform values* and *Discouraged with reform values* profiles do not seem to be applying either mastery or performance approaches to drive students' science learning. From a motivation perspective, these two profiles are concerning, given that a lack of goal-based instruction (particularly a lack of mastery approaches to instruction), coupled with low self-efficacy, is likely to be associated with less classroom opportunities for students to engage in authentic science learning, student-driven autonomy-supportive projects, and positive peer and teacher interactions (Meece et al., 2006; Perera et al., 2018, 2019; Zee & Koomen, 2016). A needed area of further research is to determine the underlying reasons for teachers' discouragement in these two profiles. For example, conditions at the district or site may result in teachers struggling with applying optimal motivational approaches to their instruction.

We also examined how science teachers' PCK and pedagogical reform values clustered into distinct profiles alongside motivation characteristics. In regard to PCK, findings somewhat aligned with our expectations that a range of profiles characterized by low to high PCK would be identified. However, in contrast to teachers' motivational dispositions, science teachers' PCK across the five profiles were close to the sample average (approximately .25 to .50 *SD* above or below the mean). Interestingly, the profile characterized by the highest levels of motivation (high mastery and performance approach, and high self-efficacy) was also characterized by the lowest level of PCK. These findings indicate that cognitive (PCK) and motivational (goal orientations, self-efficacy) characteristics do not always cluster within science teacher profiles in uniform ways. That is, holding greater knowledge about science content and effective pedagogy (e.g., anticipating students' misconceptions) is not necessarily associated with greater motivational approaches and confidence in science teaching, and vice versa. For example, lower PCK was present in both a low motivation profile (*Severely discouraged with reform values*) and a high motivation profile (*Confident with multiple goal orientations*).

10.10 | Science teachers' reform values interact in unique ways with their cognitive and motivation characteristics

Finally, two of the profiles were characterized by pedagogical reform values slightly above the mean (*Severely discouraged with reform values* and *Discouraged with reform values*), two of the profiles were characterized by pedagogical reform values slightly below the mean

(*Conventional/Traditional and performance-oriented* and *Confident and mastery-oriented*), and the fifth profile was characterized by pedagogical reform values right at the mean (*Confident with multiple goal approaches*). Surprisingly, the *Severely discouraged with reform values* profile endorsed the highest pedagogical reform values, but all of the other cognitive and motivation indices (PCK, instructional goal orientations, self-efficacy) fell below the mean. Thus, the *Severely discouraged with reform values* profile represents teachers who hold pedagogical values that endorse reform principles such as student-driven sense-making and equitable discourse opportunities, but may lack the PCK, motivation, and confidence that are important to enact instruction aligned to such pedagogical values. It is important to note, however, that there may be systemic forces at play; teachers with a strong reform-focused orientation who encounter sustained resistance from students, colleagues, and/or leadership may decrease in self-efficacy and mastery approaches over time.

On the other hand, the *Confident with mastery approach* teacher profile, which represents teachers who endorse mastery learning structures and have high confidence in their science teaching, was characterized by below average reform values. These teachers may hold pedagogical values that are more in line with traditional views of teachers as the authority and disseminator of information, yet are confident in their teaching and use mastery-based strategies to support their students' science learning. Thus, similar to the patterns in teachers' PCK, it seems that teachers' pedagogical reform values do not cluster with either PCK or motivation indicators. That is, holding a greater PCK and/or motivation and self-efficacy is not necessarily associated with higher pedagogical reform values, and vice versa. For example, higher pedagogical reform values were present in both a low motivation profile (*Severely discouraged with reform values*) and a high motivation profile (*Confident with multiple goal orientations*).

10.11 | General conclusions about and implications of science teacher profiles

Our findings have tentative implications for teacher professional learning efforts, indicating that a “one-size-fits-all” approach may not adequately meet the needs of teachers. Instead, information from the latent profiles can be used to guide more tailored professional learning experiences that are aligned to the specific configurations of each profile. These findings align with the tenants of the CAMCC, which specify that within any particular context, how teachers interpret and respond to reform messages is heavily influenced by their cognitive processing that interacts with their goals, motivations, and ability beliefs (Gregoire, 2003). For example, teachers in the *Severely discouraged but reform-oriented* profile may benefit from professional learning opportunities that have a balanced emphasis on both augmenting science PCK as well as pedagogy to support students' motivation to learn science, whereas teachers in the *Discouraged but reform-oriented* profile may benefit more from opportunities to augment their motivational approaches to teaching science. Moreover, additional research regarding why teachers fall into the discouraged profiles may indicate ways to shift their experiences of teaching to bolster their self-efficacy and mastery approaches. For example, some of these teachers may be struggling with management issues. Others may be working in a challenging school environment, where leadership and site policies should be examined.

On the other hand, the teacher profiles characterized by high motivation orientations and confidence in science teaching (*Confident and mastery oriented*, *Confident with multiple goal orientations*) may benefit from professional learning opportunities focused on deepening science and PCK, such as partnerships with university science faculty in science labs (Abell, Rogers, & Hanuscin, 2009). As science teachers' instruction spans multiple and overlapping demands, the profiles, each with distinct configurations of PCK, goal orientations, self-efficacy, and pedagogical reform values, represent an integrated system of knowledge, motivations, beliefs, and values that guide teachers' instructional decisions and interactions with students. Taken together, our results show that science teachers cluster into unique profiles that represent unique combinations of needs and strengths along these individual characteristics. In the next section, we discuss the implications of how these profiles related to teachers' instructional approaches and student outcomes.

10.12 | The relationship between science teacher profiles, antecedent teacher characteristics, and instructional and student outcomes

The results regarding the relationship between teacher profiles and antecedent teacher characteristics did not align with our predictions. Results showed that neither bachelor's degree nor school %FRL significantly predicted science teacher membership. It is possible that bachelor's degree may be a weaker predictor of middle school science teachers' cognitive and motivational characteristics compared with early childhood and primary school grades, given that secondary science teachers typically enroll in subject specific (e.g., science methods) courses as part of their teacher preparation programs, and are also required to pass standardized science assessments to obtain licensure (Olson, Tippett, Milford, Ohana, & Clough, 2015). It was also surprising that school %FRL did not significantly predict teacher profile membership, given the literature that shows that school context influences teachers' preparedness (e.g., content knowledge), motivation, as well as other affective characteristics such as morale and engagement in their professional work (in de Wal et al., 2014; Morgan et al., 2016). A possible explanation is that both bachelor's degree and school %FRL are too distal from teachers' individual characteristics examined here, and thus not strong predictors of their profile membership. For example, results from past studies showed that more proximal predictors, such as the degree of participation in professional development (Perera et al., 2019) and satisfaction in their profession (in de Wal et al., 2014) significantly predicted teacher profile membership.

In regard to the relationship between the science teacher profiles and instruction, significant differences between profiles were found for three dimensions of science instructional practice including communication, discourse, and reasoning. Interestingly, we found that the *Discouraged but reform-oriented profile* and the *Confident with multiple goal approaches* profile were associated with higher instructional practices related to the reasoning dimension compared with the *Confident and mastery-oriented* profile. The *Discouraged but reform-oriented profile* was also higher on the discourse dimension compared with the *Confident and mastery-oriented* profile. Finally, we found that the *Conventional* and the *Confident with multiple goal approaches* profiles were associated with higher ratings on the communication dimension compared with the *Confident and mastery-oriented* profile. Therefore, across all of the significant differences, the *Confident and mastery-oriented* profile was associated with lower science instructional practices in the communication, discourse, and reasoning dimensions.

At first glance, these findings may seem contradictory to the existing literature on the positive associations between high self-efficacy, high mastery approaches to instruction, and quality science instruction (Meece et al., 2006). However, it is possible that when additional teacher characteristics are accounted for (i.e., PCK, reform values), the predictive nature of teachers' motivational characteristics may change. For example, teachers in the *Confident and mastery-oriented* profile held below average pedagogical reform values, whereas teachers in both the *Discouraged but reform-oriented* and the *Confident with multiple goal approaches* profiles endorsed above average pedagogical reform values. Notably, the pedagogical reform values substantively align with the communication, reasoning, and discourse dimensions (e.g., viewing the role of teachers as a facilitator of students' sense-making, valuing opportunities for students to develop explanations through investigating scientific phenomena). This may explain why profiles of teachers who had below average motivational orientations and self-efficacy in their teaching (*Discouraged but reform-oriented*) and teachers who had below average PCK (*Confident with multiple goal approaches*), yet above average reform value alignment, were associated with greater instructional practices related to the communication, reasoning, and discourse dimensions. Additionally, the above average PCK in the *Discouraged but reform-oriented* profile, and the extreme, high motivational orientations and self-efficacy in the *Confident with multiple goal approaches* profile may work together with the higher reform values to facilitate higher science instructional practices among these teachers. On the other hand, the *Severely discouraged but reform-oriented* profile also endorsed above average pedagogical reform values, whereas the combined effects of low PCK and extremely low motivation may suppress these teachers' ability to enact this range of desirable science instructional practices.

Finally, in regard to the relationships between science teacher profiles and student outcomes, results showed that the *Confident and mastery-oriented* profile was associated with higher student science engagement and self-efficacy compared with students of teachers in the *Confident with multiple goal approaches* profile. This finding provides additional evidence that using instructional approaches that leverage students' intrinsic interests and values in exploring scientific ideas (mastery approaches) positively impacts students' engagement and self-efficacy in science over externally driven incentive systems (Bae, Hayes, O'Connor, et al., 2016; Bae, Hayes, Seitz, et al., 2016; Keller et al., 2017). Notably, our findings indicate that promoting mastery over performance approaches to science instruction is associated with higher student science engagement and self-efficacy compared with promoting multiple goals. Mastery approaches, or creating a classroom environment that fosters internal forms of student motivation (e.g., curiosity) and minimizes students' focus on external motivators (e.g., grades, awards), are important for supporting students' sense of confidence in science learning, and engagement with science learning tasks. Mastery approaches to science teaching are aligned with the Framework for K12 Science Education and the NGSS (NRC, 2012), and empirical work that suggests particularly for student groups who are traditionally marginalized in STEM, authentic opportunities to participate in science learning that draws upon students' interests to master disciplinary ideas and practices is key to supporting long-term success in science (Bae et al., 2018; Bae, Hayes, Seitz, et al., 2016; Britner & Pajares, 2006; Hayes & Trexler, 2016).

On the other hand, results also showed that the *Discouraged but reform-oriented* profile was associated with higher student science achievement compared with the *Confident with multiple goal approaches* profile. Thus, our findings indicate that while profiles characterized by high motivational approaches and self-efficacy were associated with higher affective (engagement, self-efficacy) student outcomes, the *Discouraged but reform-oriented* profile that was characterized by the highest PCK and above average pedagogical reform values (but low motivation) was associated with higher student science content knowledge. Similar patterns were reported in a variable-centered study by Keller et al. (2017), in which they found that physics teachers' PCK predicted student achievement (measured by a physics content assessment), whereas physics teachers' motivation (enthusiasm or excitement in teaching) predicted students' motivation or interest in learning physics.

Our study contributes to recent efforts that investigate teacher knowledge (cognition) and motivation together to better understand their joint influence on science teaching and learning outcomes. Our findings indicate that when both cognitive and motivational teacher characteristics are accounted for, their relationship to instructional outcomes may differ compared with results from prior studies in which cognitive and motivational characteristics are examined separately. On the other hand, it seems that the association between science teacher profiles and student outcomes follows trends identified in recent variable-centered analyses (e.g., Keller et al., 2017), in that profiles of characterized by higher knowledge (PCK) were associated with student achievement outcomes, and profiles characterized by higher motivation (goal orientations) were associated with student motivation (engagement, self-efficacy) outcomes. However, given that this is one of the few person-centered studies that have examined the nature of and predictive strengths of science teacher profiles, more work is needed to examine how such multidimensional profiles relate to science instruction and student learning.

10.13 | Limitations and future directions

Some limitations of this study need to be considered. First, the data collected was cross sectional in nature, limiting our abilities to make causal claims. Future research is needed to examine the longitudinal relationships between the predictors and outcomes of the identified science teacher profiles. Such approaches would allow us to examine whether the nature of science teacher profiles remains stable over time, as well as to examine intraindividual (or within-person) stability and change in profile membership. A second limitation of this study is that although we accounted for both cognitive and motivational teacher characteristics in the estimation of the profiles, there are other related variables that may be important to consider in future work. Notably, we only accounted for one cognitive variable, PCK, and accounting for other cognitive variables related to science teaching, such as teachers' science content knowledge, may provide a more comprehensive representation of science teacher profiles. Third, neither of the two predictors examined in this study (bachelor's degree and school %FLR) were found to be significant predictors of profile membership. Examining predictors of science teacher profiles that are more proximal to their daily professional activities, such as number of years teaching or number of hours of science professional development, may be a fruitful line of inquiry in future work. Fourth, the measures for the indicators used to create the teacher profiles (with the exception of the PCK measure) and the measure of teachers' science instruction were self-report in nature. Although self-report instruments are common to measure motivation constructs and teaching practice, our heavy reliance on self-report measures may not reflect the actual implementation of science instruction, and our findings are susceptible to mono-method bias (shared variance between teacher profiles and instruction may be explained by similarities in measurement rather than the underlying constructs assessed; Winne & Perry, 2000). Future work is needed where teacher profiles and outcomes are examined using additional measures such as direct classroom observations. Fifth, the science achievement outcome in this study was operationalized as students' understanding of grade-level science content, and future research is needed to examine other indicators of science achievement beyond content knowledge (e.g., developing evidence-based explanations, applying mathematical reasoning). Finally, because this study was conducted among middle school science teachers in the United States serving in diverse, primarily urban contexts, the profile solution identified may not generalize to other populations. Future research is needed to see if our profiles replicated in other grade levels (e.g., elementary, high school), subject areas, as well different sociodemographic (stages of career development; Klassen & Chiu, 2010) and cultural contexts.

11 | CONCLUSION

This study brings attention to the diverse nature of teacher characteristics by identifying unique science teacher profiles. Interventions with teachers often take a one size fits all approach, from policies such as accountability, to the scripted teaching approaches of the last decade, to professional development. Similarly, reform approaches tend to make assumptions that teachers are a monolithic group, assuming a common level of knowledge and/or motivation. In contrast, this study demonstrates that science teachers cluster into unique profiles, and there is likely a need for differentiation of teachers' knowledge and motivations. Finally, we show how the five science teacher profiles relate significantly to dimensions of science instruction as well as student learning outcomes.

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APPENDIX A: Correlations among observed teacher variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. BA degree	1.00														
2. School % FRL	−0.25	1.00													
3. PCK	−0.08	−0.08	1.00												
4. Mastery	0.16	0.16	−0.07	1.00											
5. Performance	−0.03	0.28	−0.10	0.400**	1.00										
6. Efficacy	−0.05	0.318*	−0.17	0.678**	0.349**	1.00									
7. Reform values	0.00	−0.21	−0.19	−0.08	−0.02	−0.03	1.00								
8. Communicating science	0.22	−0.345*	−0.12	−0.06	−0.05	−0.10	0.263*	1.00							
9. Science discourse	0.03	−0.419**	0.11	−0.13	−0.11	−0.08	−0.01	0.467**	1.00						
10. Investigation	0.08	−0.354*	0.13	−0.06	0.07	−0.05	0.04	0.357**	.509**	1.00					
11. Data collection and analysis	0.10	−0.17	−0.11	0.04	0.15	−0.05	.277*	0.502**	0.440**	0.472**	1.00				
12. Explanation and argumentation	0.19	−0.10	−0.13	−0.02	0.09	−0.06	0.19	0.06	−0.03	0.02	0.05	1.00			
13. Modeling	0.18	−0.20	0.12	0.05	0.20	−0.01	0.277*	0.266**	0.250*	0.473**	0.404**	0.383**	1.00		
14. Traditional instruction	0.15	−0.21	−0.05	−0.11	0.07	0.00	0.308*	0.609**	0.513**	0.439**	0.528**	0.229*	0.489**	1.00	
15. Prior knowledge	−0.09	−0.11	0.23	−0.08	0.00	0.02	0.04	0.391**	0.404**	0.589**	0.434**	0.06	0.503**	0.450**	1.00
M (*SD*)	0.49 (0.11)	53.16 (20.38)	0 (1.00)	4.13 (0.63)	2.95 (0.79)	3.55 (0.62)	3.86 (0.89)	3.05 (0.50)	3.43 (0.44)	3.36 (0.62)	2.89 (0.54)	3.38 (0.47)	3.99 (0.55)	3.22 (0.47)	3.97 (0.55)
Min, max	0, 1	4.80, 79.50	−3.42, 1.27	2.67, 5.00	1.67, 5.00	2.33, 5.00	1.67, 5.00	1.75, 4.25	2.20, 4.60	1.40, 5.00	1.33, 4.00	2.25, 5.00	2.67, 5.00	2.00, 4.50	2.33, 5.00

Note: $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.