Examining Forms and Frames for Science Teacher Learning Related to Large-Scale Reforms: A Multi-Manuscript Dissertation

by

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List of Abbreviations

Advanced Placement (AP)
Common Core State Standards (CCSS)
Next Generation Science Standards (NGSS)
National Science Foundation (NSF)
Professional Development (PD)
Preliminary Scholastic Aptitude Test (PSAT)
Socioeconomic Status (SES)

Abstract

This multi-manuscript dissertation is situated in the context of the large-scale, nationwide, top-down, curriculum and examination reform of the Advanced Placement (AP) science program. Teacher-level data was gathered through web-based surveys sent to all AP science teachers in the United States and corresponding student-, school-, and district-level data was provided by the College Board for all students taking redesigned AP science examinations in 2013, 2014, and 2015. Furthermore, social media discourses on Twitter were collected with automated scripts. The analyses apply a multitude of methodological techniques including hierarchical linear modeling, structural equation modeling, educational data mining, and social network analysis. The first study suggests that proactive educational policies that increase school funding, lengthen instructional time, enhance teacher quality, and encourage teachers to participate in selected PD activities can help narrow income achievement gaps and foster educational equity for students in schools that are economically disadvantaged. The second study illustrates that while PD participation can help teachers change their classroom teaching, such instructional enactments might not always relate to increases in student achievement, emphasizing the importance of better understanding the impact of school context and effective teaching practices. The third study indicates that teacher participation in collaborative online microblogging environments has the potential to adhere to design characteristics of high-quality PD and to complement more hierarchically-structured traditional PD activities. Across these three studies, this dissertation provides recommendations for changes in the educational landscape to guide transformations of teacher professional development activities, with the ultimate aim of improving student learning and narrowing achievement and opportunity gaps.

Keywords: Professional development, science education, teacher education, learning technologies, high-stakes testing, curriculum reform

Chapter One – Introduction

One of the most important objectives for education is the preparation of students for the demands of the 21 century, not only to enable individuals to succeed, but also to raise societal standards such as increased civic engagement (Baum, Ma, & Payea, 2013; R. D. Putnam, 2001), improved physical and mental health (Baum et al., 2013; Cutler & Lleras-Muney, 2006), lower unemployment rates (Baum et al., 2013), and increased economic competitiveness in a globalized world (Jerald, 2008). Large-scale nationwide reform efforts such as the Common Core State Standards Initiative (CCSS; CCSS, 2010a, 2010b), the Next Generation Science Standards (NGSS; NGSS Lead States, 2013), and the redesign of the Advanced Placement (AP) program (The College Board, 2012, 2014a, 2014b) have been initiated in the hope to positively impact the education system in the United States.

The AP science reform, which is the focus of this dissertation, constitutes a special case. Whereas states could choose to opt in to adopt the CCSS or the NGSS, the redesigned AP science examinations are administered on a national scale without providing students, schools, districts, or states a choice with respect to the adoption of the reform. If teachers do not respond to the changes, their students are at risk of lower performance on this high-stakes examination. Redesigned AP science examinations were first administered in May 2013 for AP Biology (approx. 200,000 students each year), followed by AP Chemistry in May 2014 (approx. 130,000 students each year), and AP Physics in May 2015 (approx. 150,000 students each year). College Board, the provider of the AP examinations, redesigned the AP examinations and curricula in response to recommendations of the National Research Council's *Committee on Programs for*

Advanced Study of Mathematics and Science in American High Schools (National Research Council, 2002). The AP redesign decreases the emphasis on rote memorization and the use of algorithmic-centered procedures while foregrounding deeper content understanding, underlying disciplinary concepts, scientific inquiry, science practices, critical thinking, and reasoning (e.g., Magrogan, 2014; Yaron, 2014). Many changes in the AP science examinations and curricula are consistent with the NGSS. For instance, the *Science and Engineering Practices* of the NGSS share notable communalities with the *Science Practices* of the redesigned AP science curriculum (Pellegrino, 2013). More generally, College Board's AP examinations and courses are designed to enable high-school students to receive rigorous, college-level experience in numerous subjects. The summative examinations are administered nationwide and graded on a 1-5 scale. AP examinations are high-stakes for students because success on AP examinations is often seen as beneficial for college admission and students receiving passing scores (3 or higher) might be able to use their AP scores to replace introductory college courses, depending on the colleges' credit transfer policies (Geiser & Santelices, 2006; Schneider, 2009). Research studies indicate positive associations between AP program participation and greater academic success in students' higher education careers as indicated through higher enrollment rates in 4-year postsecondary institutions (Chajewski, Mattern, & Shaw, 2011), increased college graduation rates (Dougherty, Mellor, & Jian, 2006; Hargrove, Godin, & Dodd, 2008; Mattern, Marini, & Shaw, 2013), and higher college-level grade point averages (Hargrove et al., 2008; Patterson, Packman, & Kobrin, 2011; T. P. Scott, Tolson, & Lee, 2010). These benefits of high performance on the AP examinations also increase the importance for teachers to improve students' AP performance. Teachers, teacher learning, and teacher professional development (PD) are at the heart of this dissertation as the AP science redesign provides a unique opportunity for research to examine how AP science teachers choose to prepare for this large-scale science reform.

Context for the dissertation

This dissertation is connected to a large-scale longitudinal National Science Foundation (NSF)-funded research project that explores teacher learning in relation to the redesign of the AP examinations in the sciences. This project is a collaborative endeavor in partnership with the College Board and researchers from multiple institutions including the University of Michigan, Harvard University, the University of Minnesota, and the University of Massachusetts at Boston, among others. In particular, this project consists of three strands of research. The first strand uses data from web-based surveys sent to all AP science teachers in the U.S. in 2013, 2014, and 2014, unless teachers were placed on College Board's do not contact list. The surveys inquire about teachers' PD participation, teaching background, school context, challenges with the AP redesign, AP courses, and instructional practices. The appendix includes an example of a web-based survey for AP Biology teachers. Additionally, College Board provided student- (e.g., PSAT/SAT/AP scores, family background), school- (e.g., percentage of free- or reduced-priced lunch program enrollment, ethnic make-up), and district-level data (e.g., school funding, percentage of students in district below poverty line). The second strand analyzes teacher data from case study and focus group interviews. The third strand analyzes in-depth data from a particular teacher PD activity, College Board's online AP teacher community. While this dissertation is implicitly also informed by the work of the case study and the online AP teacher community project strands, it is substantially grounded in the first project strand (i.e., quantitative analysis of data from the web-based surveys and provided by the College Board).

Conceptual frame for the dissertation

Given societal needs to support students to succeed during their school careers, it is imperative to identify ways to maximize student learning and achievement. Student success in the complex system of schooling is influenced by numerous dynamic interdependent variables. Teachers are often seen as important leverage factors to raise student achievement (Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009; Hattie, 2009, 2012; Nye, Konstantopoulos, & Hedges, 2004). Changes in teacher preparation programs are necessary to better prepare pre-service teachers to contribute to the sustainable success of large-scale educational reforms (Bybee, 2014). However, efforts to reshape teachers' knowledge, skills, and beliefs should also target in-service teachers as teachers are often not adequately prepared for standards-based teaching (Weiss, Banilower, McMahon, & Smith, 2001). Therefore, teacher PD becomes an important pathway to ensure teachers' preparedness to best support students during times of changing curricular standards.

Teacher professional learning is a complex system with interdependent and dynamic interactions among numerous elements related to teachers' professional learning experiences (Cochran-Smith, Ell, Ludlow, Grudnoff, & Aitken, 2014; Opfer & Pedder, 2011). For instance, Opfer and Pedder (2011) emphasize that teacher learning is not only influenced by PD activities but also by teachers' micro contexts (e.g., teachers' individual orientations towards learning) and macro contexts (e.g., school systems teachers are situated in). Theories of change, such as Desimone's (2009) framework for studying the effects of PD, illustrate that high-quality PD attempts to increase teachers' knowledge and skills, which enables teachers to change their classroom instruction in order to increase student learning and achievement (Figure 1).

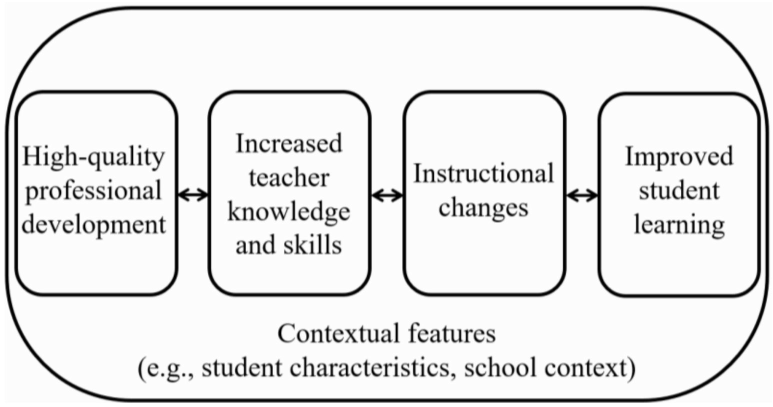

Figure 1. Framework for studying the effects of PD, by Desimone (2009).

Until the turn of the century, research mostly focused on conceptual descriptions of factors that were believed to serve as best practices for in-service teacher PD. For instance, inferences were deducted from generalizations of exemplary successful PD activities or other research subfields such as situated cognition (R. T. Putnam & Borko, 2000; Wilson & Berne, 1999). With the start of the 21st century, researchers began to more systematically analyze the impact of PD on changes of teachers' classroom instruction and student achievement using quantitative approaches (e.g., Fishman, Marx, Best, & Tal, 2003; Garet, Porter, Desimone, Birman, & Yoon, 2001). However, most of the early empirical studies primarily focused on associations of PD with teacher knowledge and/or changes of classroom practice (e.g., Banilower, Heck, & Weiss, 2007; Birman, Desimone, Porter, & Garet, 2000; Desimone, Porter, Garet, Yoon, & Birman, 2002; Garet et al., 2001; Penuel, Fishman, Yamaguchi, & Gallagher, 2007). More recently, the analysis of effects of PD on student learning and achievement gained more attention (J. P. Allen, Pianta, Gregory, Mikami, & Lun, 2011; Fishman et al., 2013; Heller, Daehler, Wong, Shinohara, & Miratrix, 2012; Roth et al., 2011). Based on the foundational study of Garet et al. (2001), Desimone (2009) summarizes decades of PD effectiveness research with a consensus that design characteristics of high-quality PD include a focus on content, active learning, coherence, duration, and collective participation. Active learning refers to PD in which teachers actively co-construct knowledge and contribute to skill acquiring processes, for instance, by reviewing of student work or feedback on teaching demonstrations. Coherence refers to PD that builds upon teachers' prior knowledge, skills, and beliefs and connects to existing curriculum implementations, standards, and policies in teachers' local contexts. Content focus refers to PD that raises teachers' content knowledge relevant for classroom instruction. Collective participation refers to PD that attracts participants from similar local contexts (e.g., teachers from the same grade-level, disciplinary concentration, or school). Duration refers to both the frequency of contact with the PD activity and the total time of exposure to the PD activity. Although these high-quality PD design characteristics and Desimone's (2009) framework are widely accepted and adopted in the field, validation studies with mixed empirical evidence (Garet et al., 2008, 2011; Jacob & McGovern, 2015) led to a call for more research to better understand how teacher PD translates into effective practice (Desimone & Garet, 2015).

Structure of the dissertation

This multi-manuscript dissertation analyzes how teachers engaged in PD in response to the AP science redesign. Although College Board does not require teachers to engage in PD with respect to the redesigned AP science program, almost all AP science teachers engaged in some form of PD (Fischer et al., 2017). PD activities teachers participate in include face-to-face workshops and activities (e.g., summer institutes, one-day workshops, one-on-one mentoring, conference participations), self-paced online courses (e.g., courses on the labs in redesigned AP curriculum), online communities (e.g., College Board's AP teacher community), and material-based PD (e.g., AP course description, teacher textbook guides, articles from magazines and journals). Thus, the AP redesign provides a unique opportunity for research on how PD relates to student performance. Given the national scope of the AP science reform, implications and recommendations from this dissertation might also benefit educational stakeholders faced with other large-scale educational reforms such as the CCSS and the NGSS. In particular, each of the three empirical studies (Chapters 2-4) in this multi-manuscript dissertation foregrounds particular aspects of Desimone's (2009) framework (Figure 2). The coloring represents the foregrounded aspects of Desimone's (2009) framework of each study and the arrow represent the directions of the analyzed relationships.

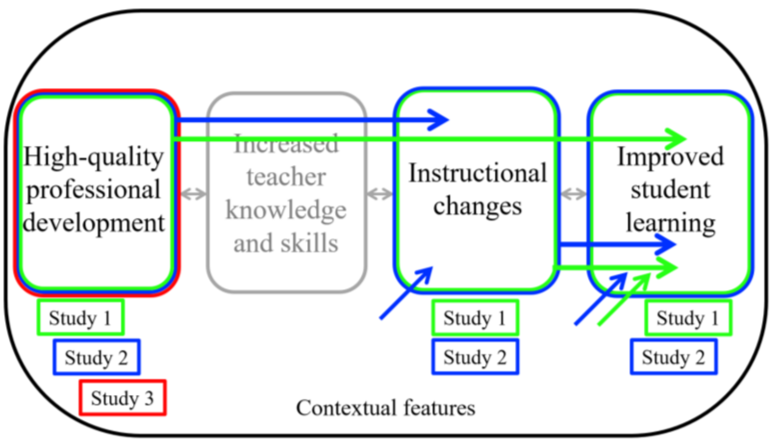

Figure 2. Situating the dissertation studies in Desimone's (2009) framework.

The first study seeks to identify ways to increase educational equity and to narrow achievement and opportunity gaps (Darling-Hammond, 2010; Reardon, 2013). It analyzes direct associations of school, teacher, teaching, and teacher PD participation characteristics with students' AP science performance in schools with large low-income student populations. The second study seeks to validate selected relationships described in Desimone's (2009) framework for studying the effects of PD. It analyzes both the direct relationship of teachers' PD participation on changes in instructional enactments and the more distant relationship of PD participation on student achievement by evaluating how teachers' classroom instruction impacted student performance on the AP science examinations. The third study is motivated by calls for research to further explore teachers' PD participation in online learning environments which might transform and complement more traditional forms of PD (Borko, Jacobs, & Koellner, 2010; Dede, 2006). This study explores how teachers' use of an online microblogging platform (Twitter) adheres to Desimone's (2009) characteristics of high-quality PD and whether such microblogging environments have potential to complement more hierarchically-structured traditional PD activities.

Although all three studies are rooted in the empirical quantitative research tradition and utilize large-scale national data sets, each study foregrounds a different methodological approach. The first study applies hierarchical linear models to account for the nesting of students within teachers/schools (Raudenbusch & Bryk, 2002) and uses Markov Chain Monte Carlo multiple imputation methods to account for missing data (Graham, 2009; Graham, Olchowski, & Gilreath, 2007). The second study uses multi-level structural equation models in a path analysis framework to explore relationships with a latent PD participation construct with variables on the teacher/school level and the student level (Hoyle, 2012; Rabe-Hesketh, Skrondal, & Pickles, 2004; Rabe-Hesketh, Skrondal, & Zheng, 2007). The third study engages in aspects of methodological pluralism (Moss & Haertel, 2016) and applies a variety of methodological approaches including educational data mining with custom Python scripts, social network analysis, qualitative two-cycle content analysis, regression analysis, and hierarchical linear modeling (Harrell, 2015; Knoke & Yang, 2008; Miles, Huberman, & Saldana, 2014; Montgomery, Peck, & Vining, 2012; Raudenbusch & Bryk, 2002; J. Scott, 2013).

Summary of dissertation study 1. The first dissertation study is entitled *Supporting students in low-SES schools to perform better-than-expected on a high-stakes test: Analyzing school, teacher, teaching, and professional development characteristics*. This quantitative study uses data (638 teachers; 11,8000 students) from schools, teachers, and students in low-socioeconomic status (SES) schools to identify factors that directly relate to student performance gains on the AP science examinations. Low-SES schools are defined as schools with at least 50% of their student population enrolled in free- or reduced-priced lunch programs. Students' AP performance gains are defined as the difference between students' actual AP science scores and students' projected AP scores predicted by their Preliminary Scholastic Aptitude Test (PSAT) scores. This study is framed by the following two research questions:

1. How do school, teacher, teaching, and PD participation characteristics compare across three AP science teacher subgroups; teachers whose students perform on average lower-than-expected, as-expected, and better-than-expected?
2. What are associations between school, teacher, teaching, and PD participation characteristics on students' AP performance gains controlling for student demographics?

The hierarchical linear models indicate that districts' per-student funding allocations, the days of the school year, teachers' knowledge and experience, and some aspects of teachers' PD participation (i.e., PD that effectively supports instruction aligned with the AP redesign, unconventional face-to-face PD activities [e.g., teacher meetings, mentoring, coaching, conference participations]) have significant direct associations with students' AP performance gains. This suggests that teachers participating in purposefully selected PD activities aligned with proactive educational policies that increase school funding and instructional time, as well as support to recruit and retain knowledgeable and experienced teachers might lead to more equitable educational opportunities for students in schools that are economically disadvantaged.

Summary of dissertation study 2. The second dissertation study is entitled *Investigating relationships between school context, teacher professional development, teaching practices, and student achievement in response to a nationwide science curriculum and assessment reform*. This quantitative study uses cross-disciplinary, longitudinal, national data (total of 7,434 teachers and 133,336 students) in an effort to validate selected relationships of Desimone's (2009) framework for studying the effects of PD. In particular, this study examines the following research questions:

1. What are the relationships among teacher professional development, teacher characteristics, and school characteristics on teachers' self-reported instructional practices?
2. What are the relationships among teachers' self-reported instructional practices, school context, and student characteristics on students' performance on the AP science examinations?

Multi-level structural equation models indicate that teachers' PD participation and teachers' perceived challenges with the AP curriculum and examination reform are associated with classroom teaching characteristics. However, such classroom practices are only weakly associated with students' AP science performance. These findings provide support for selected elements of Desimone's (2009) framework and also allude to a potential alternative explanation for studies detecting mixed results regarding Desimone's (2009) framework. While PD can change teachers' practices, these teaching practices might not be associated with increased student performance. This highlights the importance for future research that identifies effective teaching practices that lead to detectable increases on student learning and achievement metrics.

Summary of dissertation study 3. The third dissertation study is entitled *New forms of professional development: Analyzing high school science teachers' engagement in microblogging platforms for professional learning*. This observational study uses data from three hashtag-based Twitter communities (121 users; 2,040 tweets) of AP Biology teachers and provides an examination of one potential future for professional learning for teachers. In particular, this study is aligned with federal reports indicative of how digital technologies might contribute to transformations in the educational system (U.S. Department of Education, 2010, 2012, 2013). Such transformation, for teacher PD, can evolve from traditional just-in-case learning experiences (e.g., face-to-face workshops in the summer) via just-in-time learning experiences (e.g., anytime accessible self-paced online courses) to just-for-me learning experiences (e.g., online microblogging communities using Twitter). Therefore, this study investigates the following research questions:

1. Are participation structures in AP teacher Twitter communities organized similarly to more traditional, hierarchically organized professional learning activities?
2. Do AP teacher Twitter communities provide a positive, supportive environment for teachers engaging in professional learning activities?
3. Do teachers' temporal Twitter usage patterns in AP teacher Twitter communities complement more traditional forms of professional learning activities?

The findings suggest that teacher participation in Twitter communities has the potential to complement more hierarchically-structured traditional forms of PD and to adhere to design characteristics of high-quality PD. Leadership and participation structures on Twitter are less hierarchical and afford shared content creation and distribution. Professional learning on Twitter is mostly positively framed and interactions occur in a supportive environment that fosters collaboration and might help reduce teachers' perceived isolation. Temporal usage patterns highly vary among teachers, and thus, allow for a personalization of learning experiences based on teachers' needs and interests. Therefore, this study implies that collaborative online communities might contribute to the technology-driven transformations of current educational paradigms of teacher PD.

Chapter Two – When do students in low-SES schools perform better-than-expected on a high-stakes test? Analyzing school, teacher, teaching, and professional development characteristics[1]

Abstract

This empirical study analyzed data from 638 teachers and 11,800 students in low-socioeconomic status (SES) urban schools (and schools with urban characteristics) exploring associations of school, teacher, teaching, and professional development characteristics toward student performance on the revised Advanced Placement (AP) Biology and AP Chemistry examinations. The analyses indicated that districts per-student funding allocations, the days of instruction, teachers' knowledge and experience, and some aspects of teachers' professional development participation were significantly associated with student performance on AP science examinations that was better than predicted by students' Preliminary Scholastic Aptitude Test (PSAT) scores.

Keywords: Science education, high-stakes testing, school context, professional development

As we strive for increased educational equity, a focus on narrowing achievement and opportunity gaps is important (Darling-Hammond, 2010). This opportunity gap is especially problematic for students in urban and high-poverty schools (Milner, 2012a; Tate, 2008). A recurring theme in urban education research is the aspiration of providing all students with

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equitable opportunities to succeed. This often involves investigations of how to increase access for disadvantaged students to high-quality learning opportunities, attempts to identify factors that enhance student achievement and college enrollment rates, and explorations of the far-reaching influences of students' socioeconomic status (SES) on achievement and outcomes (e.g., Achinstein, Curry, Ogawa, & Athanases, 2016; Archer-Banks & Behar-Horenstein, 2012; Burks & Hochbein, 2015; Cilesiz & Drotos, 2016; Hébert & Reis, 1999; Thompson, 2004; Ward, 2006).

At the high school level, the College Board's Advanced Placement (AP) programs in the sciences and other subject areas are viewed as high-quality opportunities for students to engage in rigorous learning experiences. Research indicates that participation in AP courses and success in AP examinations are associated with greater academic success in higher education, such as higher enrollment rates in 4-year colleges (Chajewski et al., 2011), higher college graduation rates (Dougherty et al., 2006; Mattern et al., 2013), and higher college grade point averages (Hargrove et al., 2008; Patterson et al., 2011; T. P. Scott et al., 2010). Historically, urban and economically disadvantaged students had less access to AP programs than their better-off peers (Schneider, 2009). Although extensive efforts to increase access for students in urban and high-poverty schools to AP programs have been undertaken (Conger, Long, & Iatarola, 2009; Lichten, 2010; Roegman & Hatch, 2016; The College Board, 2014c; Wyatt & Mattern, 2011), tracking systems and the quantity of offerings are often barriers to enrollment in AP courses (Klopfenstein, 2004; Klugman, 2013; Schneider, 2009; Zarate & Pachon, 2006). Nevertheless, simply increasing access to AP examinations does not increase the percentage of economically disadvantaged students passing AP examinations (Hallett & Venegas, 2011; Lichten, 2010). While AP participation of low-SES students increased from 11.4% (N = 58,489) in the class of

2003 to 27.5% (N = 275,864) in the class of 2013, only 21.7% of low-SES students in the class of 2013 scored a 3 or higher (passing grade), compared with 75.3% of non-low-SES students (The College Board, 2014c). These performance discrepancies indicate that low-SES students are still less likely to obtain equitable learning opportunities despite the increased access to AP courses.

Milner's (2012b) classification of "urban" school settings emphasizes poverty, lack of resources, and high percentages of English-language learners. These are called "urban characteristics" (p. 559), and their presence may be related to student outcomes even if schools are geographically located outside of urban districts. Within urban districts, Milner (2012b) distinguishes between "urban intensive" and "urban emergent" schools based on city density. We employ Milner's (2012b) definitions in this study to explore the AP science performance of students in schools that are either urban or have urban characteristics. In these schools, where students might be expected to suffer from opportunity or achievement gaps, why do some students perform better-than-expected on the AP science examinations?

Background

The AP Program. The College Board's AP examinations and corresponding courses provide rigorous, college-level curricula for high school students in a broad variety of subjects. The summative nationwide high-stakes assessments are graded on a 1-5 scale using criterion-based rubrics. Students receiving a passing score (3 or higher) may be able to count their AP grade toward their college degree completion, depending on the policies of their institution of higher education.

The recent redesign of the AP science curriculum emerged from recommendations of the National Research Council suggesting de-emphasis of algorithmic-centered instruction and rote memorization (National Research Council, 2002). Responding to these recommendations, the College Board redesigned the AP science curriculum framework, increasing the emphasis on scientific practices, critical thinking, inquiry, and reasoning to deepen students' understanding of relevant science concepts (e.g., Magrogan, 2014; Yaron, 2014). The redesigned AP Biology examination was first administered in May 2013, followed by AP Chemistry in May 2014. Items focusing on factual knowledge or purely algorithmic procedures were reduced on the redesigned AP science examinations to include more items accessing deeper conceptual understanding and higher-order cognitive skills (Domyancich, 2014; Magrogan, 2014). Many of these changes are in line with nationwide science standards described in the Framework for K-12 Science Education (National Research Council, 2012a) and the Next Generation Science Standards (NGSS; NGSS Lead States, 2013).

These changes introduce new challenges for teachers who need to adopt to the new curricular frameworks and modify their science instruction. Therefore, teachers might be more inclined to participate in professional development (PD) activities due to the high-stakes nature of the AP examinations. Thus, this study provides a unique opportunity to explore how schools and teachers respond to this large-scale top-down mandated educational reform.

Achievement Gap Trends. Integrating data from nationally representative studies, Reardon (2011, 2013) describes how the income achievement gap for students in the top and bottom 10th income percentile increased from the mid-1940s to the turn of the century by about 0.5 standard deviations. The influence of SES on student achievement is also documented in large-scale international comparative studies. For instance, the 2012 Program for International Student

Assessment (PISA) study indicates that 15% of U.S. students' performance variation is attributable to students' SES (Organization for Economic Co-Operation and Development [OECD], 2013a, 2013b). On the contrary, Reardon (2011, 2013) finds that achievement gaps due to race/ethnicity narrowed from the 1950s to the turn of the century with a decrease in the African American/White achievement gap of about 0.6 standard deviations, about 0.5 standard deviations smaller compared with the income achievement gap. Nevertheless, an SES-based effect on academic performance persists (e.g., Bohrnstedt, Kitmitto, Ogut, Sherman, & Chan, 2015; Milner, 2012c). For instance, the 2011 National Assessment of Educational Progress (NAEP) program evaluation ascertained that the African American/White achievement gap further decreases when controlling for SES (Bohrnstedt et al., 2015). Given that SES-based performance discrepancies on the AP examinations mirror general trends of widening income achievement gaps, this study exclusively focuses on low-SES urban schools (and schools with urban characteristics as defined by Milner, 2012b). Accounting for the intersection of race and class on student achievement, racial/ethnic background variables were included in the analyses as student-level covariates.

Theoretical framework

Hundreds of thousands of students and tens of thousands of AP science teachers are affected by the mandated, nationwide, top-down implementation of the revised AP science curricula and examinations. Although students and teachers share responsibility for student learning (Patrick, Mantzicopoulos, & Sears, 2010), teachers and teacher learning are instrumental for improving student learning and achievement (e.g., Ball & D. K. Cohen, 1999; D. K. Cohen & Ball, 1999; Darling-Hammond et al., 2009; Hattie, 2009). Thus, exploring urban students' performance on the redesigned AP science examinations is framed by an examination of how teachers navigate this change within their specific school contexts, and how schools support teachers in their AP science teaching.

This study employed a modified version of Opfer and Pedder's (2011) “Dynamic Model of Teacher Learning and Change.” Employing a complexity theory perspective, Opfer and Pedder (2011) describe how three recursive and autopoietic subsystems, the school-level system, the individual teacher-level system, and the PD-level system affect teacher learning and changes in classroom practices. This study modified Opfer and Pedder's (2011) framework in three ways: First, emphases on specific elements within each subsystem are slightly shifted. For instance, instead of foregrounding collective norms, structures, and belief systems about learning on the school-level system, this study highlighted the availability/scarcity of resources, given the study’s focus on low-SES school settings. Second, Opfer and Pedder (2011) emphasize the recurrence, interdependence, and overlap of elements within and across subsystems. Conceptually, this study concurs with these notions but the data sources with their underlying variable structures posed some challenges on modeling such relationships. Third, Opfer and Pedder (2011) limit their framework to teacher- and school-level elements. This study extended this approach by connecting teacher learning and classroom practices to student achievement in accordance with other conceptualizations of teacher learning (Borko, 2004; Darling-Hammond et al., 2009; Desimone, 2009).

The challenges of urban contexts. In addition to the demands of acclimating to the AP redesign, the context of low-SES urban schools (and schools with urban characteristics) poses additional challenges for students and teachers that might widen opportunity gaps. High-poverty schools might suffer from substantially lower district expenditures, poorly equipped classrooms, higher student–teacher ratios, more out-of-field teaching, difficulties to recruit and retain highly qualified teachers, and infrequent implementations of effective teaching (Biddle & Berliner, 2003; Boyd, Lankford, Loeb, Ronfeldt, & Wyckoff, 2011; Goldhaber, Lavery, & Theobald, 2015; P. T. Hill, Guin, & Celio, 2003; Ingersoll, 1999; Isenberg et al., 2013) which illustrates underlying conditions that contribute to existing opportunity gaps.

Teacher and teaching characteristics. On the teacher level, individual teacher characteristics and the quality of instruction are widely regarded as important preconditions for students' success on the AP science examinations (Hallett & Venegas, 2011; Klopfenstein, 2004; Lichten, 2010). Although teachers' knowledge and expertise is related to teaching quality, science content knowledge alone is insufficient for high-quality science teaching (e.g., Abell, 2007; Magnusson, Krajcik, & Borko, 1999). To better describe the different knowledge domains necessary for high-quality instruction, Ball, Thames, and Phelps (2008) extend Shulman's (1986) triad of "subject matter content knowledge," "pedagogical content knowledge," and "curricular knowledge" with the more nuanced multidimensional "Content Knowledge for Teaching" framework. Ball et al. (2008) describe the six knowledge domains as "common content knowledge" ("knowledge and skill[s] used in settings other than teaching" [p. 399]), "specialized content knowledge" ("knowledge and skill[s] unique to teaching" [p. 400]), "horizon content knowledge" ("awareness of how [disciplinary] topics are related over the span of [the discipline] included in the curriculum" [p. 403]), "knowledge of content and students" ("knowledge that combines knowing about students and knowing about [the discipline]" [p. 401]), "knowledge of content and teaching" ("combines knowing about teaching and knowing about [the discipline]" [p. 401]), and "knowledge of content and curriculum" (which is identical to Shulman's [1986] "curricular knowledge"). The greater teachers' expertise in each of these domains, the more likely they are to engage in high-quality instruction using "high-leverage practices," which Ball and Forzani (2011) define as “those activities of teaching which are essential; . . . competent engagement in them would mean that teachers are well-equipped to develop other parts of their practice and become highly effective professionals” (p. 19). Examples of such high-leverage practices include “explaining and modeling content, practices, and strategies”; “diagnosing particular common patterns of student thinking and development in a subject matter domain”; and “setting up and managing small group work” (TeachingWorks, 2016).

Teacher PD. Due to the high-stakes nature of the AP examinations and the major curriculum changes of the AP redesign, we believe that AP science teachers have a strong incentive for engaging in PD. The ultimate goal of PD is to increase student learning and achievement (Darling-Hammond et al., 2009; Loucks-Horsley, Stiles, Mundry, Love, & Hewson, 2010). An accepted theory of change asserts that teacher participation in “high-quality” PD results in increases in teacher’s knowledge and experience leading to instructional changes that eventually affect student learning and achievement (Desimone, 2009; Fishman et al., 2013, 2003; Loucks-Horsley & Matsumoto, 1999). A decade of systematically conducted empirical research studies on best practices of PD activities (e.g., Banilower et al., 2007; Borko, 2004; Fishman et al., 2013, 2003; Garet et al., 2001; Penuel et al., 2007; Roth et al., 2011) led to a consensus of core PD characteristics constituting “high-quality” PD—content focus, active learning, coherence, duration, and collective participation (Desimone, 2009). Content focus refers to PD that enhances teachers’ expertise in knowledge domains. For example, PD might provide examples of how to support students’ scientific inquiry processes during laboratory investigations. Active learning refers to PD that emphasizes teachers’ active engagement in thinking processes to self-construct knowledge. For example, PD might provide opportunities to review student work, observe expert teaching, or being observed during own classroom teaching.

Coherence refers to PD that is aligned with existing curriculum frameworks, assessments, and school/district/state/nationwide reforms and policies, as well as with teachers' prior PD experiences, instructional practices, knowledge, and beliefs. For instance, first-year teachers might participate in very different PD activities compared with veteran AP teachers. Duration refers to both the total contact time and the time span in which the PD takes place. For example, the total contact time and time span of College Board's 4- to 5-day summer institutes are predefined, whereas participation in online teacher communities might vary greatly in both total time and time span. Collective participation refers to PD that is attended by multiple teachers from the same school, department, or grade facilitating collegial and supportive relationship building among colleagues. For example, teachers who collectively participate in the same PD activity might communicate about PD content after the official end of the PD activity, which might foster sustainable changes of classroom practices. Although prior research established these "high-quality" PD characteristics, systematic empirical explorations relating teachers' exposure to each of the "high-quality" PD features toward student achievement are still needed.

Research questions

This study is framed by the following two research questions focusing on the identification of factors that might narrow opportunity gaps in urban school (and schools with urban characteristics):

Research Question 1: How do school, teacher, teaching, and PD participation characteristics compare across three AP science teacher subgroups; teachers whose students perform on average *lower-than-expected*, *as-expected*, and *better-than-expected*?

Research Question 2: What are associations between school, teacher, teaching, and PD participation characteristics on students' AP performance gains controlling for student demographics?

Method

Data sources. This study is part of a larger longitudinal research project that explores how student outcomes in response to changes introduced by the AP redesign are related to teachers' PD patterns. The data used in this study were gathered from web-based surveys sent to AP Biology and AP Chemistry teachers in May 2014 inquiring about teacher demographics (e.g., age, gender), teaching background (e.g., teaching experience, university education), PD participation (e.g., "high-quality" PD features), general attitudes toward PD (e.g., perceived PD effectiveness, belonging to professional organizations), AP science course characteristics (e.g., length of instruction, number of students/sections/preps), AP science instruction and school context (e.g., teaching practices, administrative support), and concerns (e.g., challenges with the AP redesign). Prior to the first administration in 2013, the surveys were piloted with selected AP teachers and critiqued by an advisory board with expertise in science education, PD, and measurement. Survey items were validated using a cognitive interview methodology (Desimone & Le Floch, 2004).

The College Board provided student- and school-level data for all students taking AP science examinations, which included student demographics (e.g., racial/ethnic background, parental educational attainment, English-language learner status), students' PSAT and AP science scores, school characteristics (e.g., enrollment in free- and reduced-price lunch programs, school neighborhood), and district-level information (e.g., per-student funding allocations).

Population and sample. The overall student population consisted of all students taking the AP Biology ($N_{Bio,S}$ = 203,304) and AP Chemistry ($N_{Chem,S}$ = 133,323) examination in May 2014. Web-based surveys were sent to every AP Biology ($N_{Biol,T}$ = 9,511) and AP Chemistry ($N_{Chem,T}$ = 7,098) teacher in the nation, unless they were placed (by personal request) on College Board's Do Not Contact List. The survey was completed by 2,482 AP Biology (response rate = 26.10%) and 2,563 AP Chemistry (response rate = 36.11%) teachers, which are considered good response rates for web-based surveys with this population size (Shih & Fan, 2009). Non-response analyses using non-parametric Mann–Whitney tests indicated that survey responders taught slightly higher achieving students on PSAT (Biology: $z = -9.35$, $p < .001$, $d = -0.052$; Chemistry: $z = -5.60$, $p < .001$, $d = -0.039$) and AP examinations (Biology: $z = -17.46$, $p < .001$, $d = -0.095$; Chemistry: $z = -24.71$, $p < .001$, $d = -0.143$). Furthermore, schools with survey respondents enrolled slightly lower percentages of students eligible for free- or reduced-price lunch programs (Biology, $z = 15.89$, $p < .001$, $d = 0.094$; Chemistry, $z = 18.28$, $p < .001$, $d = 0.112$). However, the effect sizes (using Cohen's *d*) were very small, such that this analysis might be generalizable to the AP science teacher population.

To focus on factors related to improved student learning and achievement in low-SES urban schools (and schools with urban characteristics), the research questions were explored using a reduced sample. This reduced sample included all observations of teachers who responded to the survey and taught in schools with at least 50% of their student body enrolled in free- or reduced-price lunch programs yielding a sample size of 11,800 AP students (Biology: 6,410 students; Chemistry: 5,390 students) and 638 AP teachers (Biology: 318 teachers, Chemistry: 320 teachers).

Of the 11,000 students, 43.4% students were taught in schools that Milner (2012b) would consider "urban intensive" or "urban emergent." The remaining 56.6% students were taught in schools that College Board did not classify as urban schools based on National Center for Education Statistics (NCES) Local Code classification and ZIP code information. However, these schools exhibited features that Milner (2012b) describes as "urban characteristic"—high levels of poverty, scarcity of resources, and increased numbers of English-language learners. High levels of poverty are related to low SES which is often measured with students' eligibility for free or reduced-price lunches (National Center for Education Statistics, 2011) and/or parental educational attainment (National Center for Education Statistics, 2012). Given the subgroup sampling strategy, at least 50% of students were eligible for free or reduced-price lunches in the selected schools. Parental median education levels were similarly low for students in schools with urban characteristics (mother: some college; father: business/trade school) compared with "urban intensive" and "urban emergent" schools (mother, father: some college) and considerably lower compared with students not included in the low-SES sample (mother, father: bachelor's or 4-year college degree). Regarding the scarcity of resources, overall district funding for schools with urban characteristics in the low-SES sample averaged about US$8,500 per student. In contrast, "urban intensive" and "urban emergent" schools overall district expenditures were slightly higher averaging about US$9,000 per student. Similarly, overall district expenditures for schools not included in the low-SES sample averaged about US$9,000 per student. Regarding the number of English-language learners in the community, 17.5% of students in schools with urban characteristics in the low-SES sample did not report English as their first language compared with 11.0% of students not included in the low-SES sample. Thus, the low-SES sample can be considered as a good representation of students and teachers in "urban" settings.

Analytical methods. Before conducting statistical analyses, data preparation strategies were applied using the full sample, separated by science discipline to reduce sampling biases. *Missing data* were imputed using Markov Chain Monte Carlo multiple imputation methods with 150 iterations and 40 imputations yielding power falloffs less than 1% compared with full-information maximum-likelihood approaches (Graham, 2009; Graham et al., 2007). For both student- and school-level imputation models, auxiliary variables were used to improve the imputed estimates. The percentage of missing data was below 5% for almost all variables.

Composite variables were computed using exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) on two randomly sampled equal-sized independent data sets, separated by science discipline. EFA was conducted using the Guttman–Kaiser criterion and scree plot analyses to determine the number of retained factors. Items were gradually excluded from composite variables for factor loadings below 0.25 thresholds, which is conservative compared with conventionally used thresholds of 0.3 to 0.4 (Grice, 2001). Assuming that factors were correlated to each other, parameters were extracted using normalized oblimin oblique rotation methods. CFA used the maximum-likelihood estimation method. Model fits were compared based on the EFA, goodness-of-fit statistics, and likelihood-ratio tests. Bartlett factor scores were computed to create standardized factor scores (DiStefano, Zhu, & Mindrila, 2009). Cronbach's α was computed to estimate the reliability of each composite variable.

Exploring the first research question, school-, teacher-, and teaching-level variables were compared between three groups of AP science teachers: teachers whose students performed on average *lower-than-expected*, *as-expected*, and *better-than-expected* on the AP science examination than predicted by students' PSAT scores. To independently test differences across the three groups, parametric one-way ANOVA or non-parametric Kruskal–Wallis *H* tests were conducted. Observations were independent because teachers were uniformly distributed across all three groups. Normality was tested through graphing plots of each variable because ANOVAs are fairly stable against non-normal distributions. Homogeneity of variance was tested using Levene's test based on mean values if the data were normally distributed, Brown-Forsythe's test based on the median if the data were heavily skewed, or Brown-Forsythe's test based on a trimmed mean if the data were heavily tailed. Multiple-group comparisons were conducted using Tukey–Kramer or post hoc Mann–Whitney tests with Bonferroni corrections. Effect sizes were measured using eta-squared; 0.04 (recommended minimum effect size), 0.25 (moderate effect), 0.64 (strong effect; Ferguson, 2009).

For the second research question, direct associations of school, teacher, teaching, and PD participation characteristics with students' AP performance gains were explored using two-level fixed-effect hierarchical linear models (HLMs) with robust standard errors (Raudenbusch & Bryk, 2002), controlling for student-level covariates. Due to missing student–teacher identifiers, schools with more than one AP science teacher in the corresponding discipline were removed from the sample. Therefore, a two-level approach nesting students within teachers/schools was sufficient. Prior to the HLM analyses, the underlying HLM assumptions (Raudenbusch & Bryk, 2002) were tested, and the intraclass correlation coefficient (ICC) was computed. For instance, the observations were independent because student–teacher combinations were uniformly distributed in the data. Multicollinearity of independent variables was tested calculating variance inflation factors on both levels. Homoskedasticity of residuals was tested similarly to Research Question 1.

Measures. The *dependent variable* used for the HLM analyses was a continuous variable comparing students' actual performance on the AP science examination with their predicted performance based on their PSAT examination scores. Students' PSAT performance was used as an academic achievement measure prior to students' enrollment in AP science courses. This difference between students' actual AP science scores and students' predicted AP science scores was called "AP performance gain" (Biology: $n = 6{,}410$, $M = -0.110$, $SD = 0.650$; Chemistry: $n = 5{,}390$, $M = -0.167$, $SD = 0.834$). Positive AP performance gains indicated that students performed better-than-expected on the AP examination than predicted by the PSAT examination and vice versa. The rationale for using students' AP performance gains instead of students' AP science scores is twofold: First, teachers were classified into groups based on their students' AP performance gains. As prior knowledge often strongly predicts current knowledge, teacher-level effects on student learning would be more difficult to detect if such teacher groupings were not controlling for students' prior knowledge. Second, this study attempted to identify factors related to improved student performance beyond students' predicted AP scores by the PSAT examination attempting to generate more intuitive implications for educational policy makers and practitioners.

The data suggest that PSAT scores strongly correlate with AP science scores, $r = .672$, $p < .001$, which is consistent with prior research (Ewing, Camara, & Millsap, 2006; Lichten, 2010; Lichten & Wainer, 2000), such that students' PSAT scores can be viewed as predictors of AP science performance. Students' AP performance gains were computed separate for each science discipline applying linear regressions using every student's PSAT (*x*-axis) and AP score (*y*-axis). The distance (on the *y*-axis) between students' actual AP score and students' projected AP score represented students' AP performance gain. A positive difference indicated that a student was performing better-than-expected on the AP examination and vice versa. To identify teachers whose students performed on average better-than-expected, a continuous variable averaging students' performance gains for all students taught by one teacher (*n* = 638, *M* = –0.179, *SD* = 0.427) was computed.

Table 1. Single-indicator independent variables.

	Description	Range	*M* (*SD*)
Level 1 (student characteristics)			
English language[a]	Students' first language (0 = other than English, 1 = English or English and another language)	0, 1	0.808
White[a]	Students' ethnicity: White	0, 1	0.373
Black[a]	Students' ethnicity: Black/African American	0, 1	0.151
Asian[a]	Students' ethnicity: Asian/Asian American or Pacific Islander	0, 1	0.183
Hispanic[a]	Students' ethnicity: Mexican/Mexican American/ Puerto Rican, or other Hispanic/Latino/Latin American	0, 1	0.279
Native[a]	Students' ethnicity: American Indian/Alaska Native	0, 1	0.010
Level 2 (school characteristics)			
District funding[b]	Total per-student expenditures in US$1,000	[3.25, 13.00]	9.00 (2.34)
Length of school year[b]	Length of school year (days)	[1, 351]	275.78 (33.08)
Charter[a]	School is charter school	0, 1	0.204
Enrollment criteria[a]	Enrollment criteria for AP course	0, 1	0.549
Level 2 (teacher and teaching characteristics)			
Female[a]	Teachers' sex is female	0, 1	0.651
Disciplinary major[a]	Major in corresponding discipline, life sciences (Biology)/physical sciences (Chemistry)	0, 1	0.674
Labs[b]	Number of completed laboratory investigations from AP laboratory guide	[0, 16]	6.27 (3.62)

Note. [a]Dichotomous variable ("0"—no and "1"—yes, unless otherwise indicated) [b]Continuous variable.

Single-indicator *independent variables* were included in the analyses on the student-, school-, teacher-, and teaching level (Table 1) as covariates to reduce confounding effects. Student-level variables included students' English-language learner status and dichotomous variables capturing students' racial/ethnic background; the latter were included to account for the intersectionality of race and class on student achievement. School-level variables included districts' per-student funding allocations, the length of the school year, and whether enrollment criteria for AP science courses existed. Teacher- and teaching-level variables included teachers' gender, major, and the number of completed laboratory investigations from the AP laboratory guide.

Table 2. Composite independent variables, excluding teachers' PD participation.

	Description	α	Range	*M* (*SD*)
Level 1 (student characteristics)				
Parents' education[a]	Average parental educational attainment (1 = Grade school, 2 = Some high school, 3 = High school diploma, 4 = Business/trade school, 5 = Some college, 6 = Associate's degree, 7 = Bachelor's degree, 8 = Some graduate or professional school, 9 = Graduate/professional degree)	—	[1, 9]	4.73 (2.22)
Level 2 (school characteristics)				
Administrative support[b]	Composite: (a) principal understands challenges for AP science students,[c] (b) principal understands challenges for AP science teachers,[c] (c) principal supports PD,[c] (d) lighter teaching load for AP science teachers,[c] (e) fewer out-of-class responsibilities for AP science teachers,[c] (f) AP science is given additional funding,[c] (g) availability of equipment to perform labs,[d] (h) availability of expendable (consumable) supplies to perform labs[d]	.73	[−2.99, 2.29]	−0.212 (1.125)
AP workload[b]	Composite: (a) number of students across all AP Biology/Chemistry sections,[b] (b) number of AP Biology/Chemistry sections,[b] (c) weekly number of preps[b]	.65	[−1.61, 4.97]	−0.301 (0.865)
Level 2 (teacher and teaching characteristics)				
Teachers' knowledge and experience[b]	Composite: (a) years teaching high school science,[b] (b) years teaching AP Biology/Chemistry,[b] (c) number of science-teaching-related professional organizations,[b] (d) number of conference attendances within the past 3 years,[b] (e) years serving as AP reader, (f) years serving as AP consultant,[b] (g) time of assignment to teach AP science[a]	.55	[−1.94, 3.77]	−0.330 (0.857)
PD inclination[b]	Composite: (a) importance of PD in instructional performance,[c] (b) importance of PD in student performance,[c] (c) effectiveness of self-teaching compared with formal PD participation,[c] (d) efficacy of PD participation,[c] (e) enjoyment of participation in face-to-face PDs[c]	.81	[−4.52, 1.81]	0.168 (1.055)
Challenges with the AP redesign[b]	Composite: Challenges with (a) Biology/Chemistry content,[c] (b) organization of Biology/Chemistry content,[c] (c) labs,[c] (d) inquiry labs,[c] (e) format of questions/problems/exams,[c] (f) application of science practices,[c] (g) developing new syllabi,[c] (h) understanding the "exclusion statements,[c]" (i) designing new student assessments,[c] (j) using the textbook,[c] (k) working with new/different textbooks,[c] (l) pacing of course,[c] (m) moving students to conceptual understandings of Biology/Chemistry[c]	.87	[−2.91, 3.17]	0.179 (1.068)
Enactment: AP practices[b]	Composite: (a) students work on laboratory investigations,[c] (b) provide guidance on integrated content questions,[c] (c) provide guidance on open/free response questions,[c] (d) students report laboratory findings to another,[c] (e) students perform inquiry laboratory investigations[c]	.65	[−4.88, 3.19]	0.051 (1.220)
Enactment: AP curriculum[b]	Composite: (a) refer to the "Big Ideas" of Biology/Chemistry,[c] (b) use science practices outside of the classroom,[c] (c) refer how enduring understandings relate to the "Big Ideas,[c]" (d) refer to learning objectives from AP curriculum,[c] (e) refer to the curriculum framework[c]	.83	[−2.53, 2.40]	0.250 (1.088)

Note. [a]Ordinal variable, treated as continuous in subsequent analyses; [b]Continuous variable; [c]5-point Likert-type scale item; [d]4-point Likert-type scale item.

Similarly, composite *independent variables* were included on the student-, teacher-, and school level (Table 2). Student-level composite independent variables included parents' educational level. School-level composite independent variables included teachers' perceived administrative support and AP workload. Teacher-level composite independent variables included teachers' knowledge and experience, PD inclination, enactment of AP redesign practices, enactment of AP redesign curricular elements, and challenges with the AP redesign.

Table 3. Description of teachers' PD participation rates.

	Duration	*n*
Conventional PD activities		
F2F: AP summer institute[a]	2	360
F2F: AP fall workshop[a]	1	125
F2F: Transition to inquiry-based labs workshop[a]	1	35
F2F: Day with AP reader[a,b]	1	14
F2F: Laying the foundation, by NMSI[b]	2	16
F2F: BSCS Leadership Academy, by BSCS and NABT[b]	2	3
Online: Transition to inquiry-based labs[a]	1	18
Online: Introduction to AP Biology/Chemistry[a]	1	19
Online: AP Central Webcast: Exploring atomic structure using photoelectron spectroscopy[a,c]	1	26
Online community: AP online teacher community[a]	[d]	299
Online community: NSTA online community	[d]	49
Unconventional PD activities		
F2F: District/regional/local college/teacher-initiated meetings	—	123
F2F: Mentoring/coaching one-on-one or with other teachers	—	92
F2F: Conferences or conference sessions	—	55
Materials: AP course and exam description[a]	—	609
Materials: AP lab manual[a]	—	543
Materials: Textbook teacher guide and related materials	—	457
Materials: Instructional materials developed by colleagues	—	506
Materials: Articles from magazines or journals	—	315
Materials: Video resources	—	385

Note. NMSI = National Math + Science Initiative; BSCS = Biological Sciences Curriculum Study; NABT = National Association of Biology Teachers; NSTA = National Science Teachers Association; [a]Provided by the College Board; [b]Biology only; [c]Chemistry only; [d]Teacher self-reports.

Teachers' PD participation was measured for conventional and unconventional PD activities (Table 3). Conventional PD activities were described through 5-point Likert-type scales describing the "high-quality" PD features active learning experiences, responsiveness to teachers' needs and interests, focus on student work, modeling teaching, and opportunities to build relationships with colleagues. An additional variable inquired whether teachers felt effectively supported for teaching AP by their PD participation. The duration of PD activities was classified as 1 = low duration (≤ 8 hr), 2 = moderate duration (8-40 hr), and 3 = long duration (>40 hr).

Composite variables of conventional PD activities for each PD feature were based on total "exposure," summing up the Likert-type scale scores (0-4) for all PD teachers participated in. Accounting for the dosage of PD exposure, each Likert-type scale score was multiplied by the corresponding PD duration score. These scalar products were added across all PD teachers participated in to generate composite variables for each PD feature. For unconventional PD activities, the composite variables described the total number of unconventional PD activities teachers engage in, separated by face to face and materials (Table 4).

Table 4. Teachers' PD participation patterns.

	Range	*M*	*SD*
Conventional PD characteristics			
Active learning	[0, 12]	2.18	2.06
Responsive agenda	[0, 16]	3.24	2.65
Focus on student work	[0, 16]	2.39	2.55
Modeling teaching	[0, 17]	2.62	2.67
Building relationships	[0, 17]	3.54	2.84
Effective support	[0, 18]	3.86	3.12
Unconventional PD activities			
Face to face	[0, 3]	0.42	0.73
Materials	[0, 6]	4.41	1.34

Findings

Key characteristics of the AP science teacher population. The first research question attempted to identify distinctive features of the AP science teacher population in low-SES urban schools (and schools with urban characteristics). Teacher characteristics were compared among three AP science teacher groupings: teachers whose students perform on average more than one third of an AP science score lower (*lower-than-expected, n* = 232), within a range of one third below and above their predicted score (*as-expected, n* = 339), and more than one third of an AP science score higher than students' predicted score (*better-than-expected, n* = 67). Table 5 describes omnibus between-groups effects between teacher groupings.

The analysis indicated significant differences for some school-, teacher-, teaching-, and PD-related characteristics across the student performance-based teacher groupings (Table 5). This suggested that the composition of the three teacher groups was based on different profiles. Differences in student participation in low-SES urban schools (and schools with urban characteristics) did not seem to occur at random or only with respect to inherent student characteristics. Further analyses on the significant differences of the omnibus tests using multigroup comparisons yielded interesting insights (Table 6).

Table 5. Level 2 Omnibus group comparisons using ANOVA and Kruskal–Wallis H tests.

	Test	F or χ^2	η^2
School characteristics			
District funding	ANOVA	4.58*	.014
Days of school year	Kruskal–Wallis	9.40**	.139
Administrative support	ANOVA	.29	.001
AP workload	Kruskal–Wallis	2.92	.013
Teacher and teaching characteristics			
Knowledge and experience	Kruskal–Wallis	14.20**	.317
PD inclination	Kruskal–Wallis	1.94	.006
Labs	Kruskal–Wallis	4.40	.030
Challenges with AP redesign	ANOVA	3.31*	.010
Enactment: AP practices	Kruskal–Wallis	4.08	.026
Enactment: AP curriculum	ANOVA	1.27	.004
PD characteristics			
Active learning	Kruskal–Wallis	4.64	.034
Responsive agenda	Kruskal–Wallis	8.54*	.114
Focus on student work	Kruskal–Wallis	11.06**	.192
Modeling teaching	Kruskal–Wallis	5.13	.041
Building relationships	Kruskal–Wallis	6.00	.057
Effective support	Kruskal–Wallis	6.79*	.072
Unconventional PD: F2F	Kruskal–Wallis	3.15	.016
Unconventional PD: Materials	Kruskal–Wallis	9.54**	.143

Note. *$p < .05$. **$p < .01$. ***$p < .001$.

School-level variables. ANOVA indicated significant differences regarding schools' overall district funding allocations between the three teacher groups, $F(2, 635) = 4.58$, $p < .05$, $\eta^2 = .014$. Tukey–Kramer multiple-comparison tests indicated significantly lower district-level per-student funding allocations to schools of teachers in the *lower-than-expected* group (M = US$8,652, SD = US$2,397) compared with the *as-expected* (AE) group (M = US$9,144, SD = US$2,245), $TK = 3.51$, $p < .05$, and the *better-than-expected* group (M = US$9,463, SD = US$2,457), $TK = 3.56$, $p < .05$. Kruskal–Wallis H tests indicated small significant differences in the days of the school year across the three teacher groups, $\chi^2(2, 635) = 9.40$, $p < .01$, $\eta^2 = .139$. Post hoc Whitney–Mann U tests with Bonferroni corrections indicated that the number of days in the school year was significantly lower for teachers in the *lower-than-expected* group (M = 270.90, SD = 39.68) compared with the AE teacher group (M = 278.43, SD = 28.95), $U = -2.96$, $p < .01$. These findings suggested that contextual features for teachers in the *lower-than-expected* group were substantially less favorable for providing equitable learning opportunities to students because schools of these teachers were given considerable less district funding and teachers needed to prepare students for the AP examinations in considerably fewer days of instruction.

Table 6. Level 2 Post hoc multiple-group comparisons.

	Lower-than-expected [0]		As-expected [1]		Better-than-expected [2]		0→1	1→2	0→2
	M	*SD*	*M*	*SD*	*M*	*SD*	*p*	*p*	*p*
School characteristics									
District funding	8.65	2.40	9.14	2.25	9.46	2.56	*	*ns*	*
Days of school year	270.9	39.7	278.4	29.0	279.3	25.0	**	*ns*	*ns*
Teacher characteristics									
Knowledge and experience	–0.462	0.819	–0.289	0.872	–0.080	0.849	*	*	**
Challenges with AP redesign	0.316	1.096	0.118	1.054	0.011	1.000	*ns*	*ns*	*ns*
PD characteristics									
Responsive agenda	2.96	2.60	3.53	2.72	2.77	2.31	**	*ns*	*ns*
Student work	2.26	2.59	2.60	2.55	1.81	2.39	*	**	*ns*
Effective support	3.52	2.99	4.17	3.19	3.49	3.06	*	*ns*	*ns*
Unconventional PD: Materials	4.26	1.34	4.55	1.37	4.25	1.17	**	*	*ns*

Note. *$p < .05$. **$p < .01$. ***$p < .001$.

Teacher-level variables. Kruskal–Wallis *H* tests indicated moderate significant differences across the three groups regarding teachers' knowledge and experience, $\chi^2(2, 635) = 14.20$, $p < .01$, $\eta^2 = .317$. Post hoc Whitney–Mann *U* tests with Bonferroni corrections indicated that teachers' knowledge and experience in the *better-than-expected* group ($M = -0.080$, $SD = 0.849$) were significantly higher compared with teachers in the AE group ($M = -0.289$, $SD = 0.872$), $U = -2.20$, $p < .05$, and the *lower-than-expected* (LTE) group ($M = -0.462$, $SD = 0.819$), $U = -3.44$, $p < .01$; the difference between the AE and LTE groups was also significant, $U = -2.49$, $p < .05$. Note that all mean values were negative because the composite variables were computed using the "full sample" of all AP science teachers responding to the web-based surveys (and not the low-SES sample). Regarding teachers' perceived challenges with the AP redesign, ANOVA indicated significant differences across the three teacher groups below the recommended minimum effect size, $F(2, 635) = 3.31$, $p < .05$, $\eta^2 = .010$. Consequently, Tukey–Kramer multiple-comparison tests did not indicate significant differences across the three teacher groups. These findings suggest that the profiles of teachers in the three groups are similar regarding most teacher and teaching characteristics. The exception was that teachers in the groups with higher average student achievement gains were more knowledgeable and experienced. This raises concerns that students whose AP performance was considerably lower than anticipated and who might have needed guidance from highly qualified teachers were not taught by the most able teachers.

PD characteristics. Kruskal–Wallis *H* tests indicated small significant differences across the three groups regarding teachers' combined ratings of the responsiveness of the agenda of the PD to teachers' interests and needs, $\chi^2(2, 635) = 8.54$, $p < .05$, $\eta^2 = .114$, the focus of the PD on student work, $\chi^2(2, 635) = 11.06$, $p < .01$, $\eta^2 = .192$, and how effective teachers felt supported for teaching the AP redesign, $\chi^2(2, 635) = 6.79$, $p < .05$, $\eta^2 = .072$. In addition, teachers' unconventional PD participation through materials significantly differed across the three groups, $\chi^2(2, 635) = 9.54$, $p < .01$, $\eta^2 = .143$. Post hoc Whitney–Mann *U* tests with Bonferroni corrections indicated that teachers in the AE group had significantly higher ratings, compared with the LTE group, of their PD experience being responsive to their interests and needs (AE: $M = 3.53$, $SD = 2.72$; LTE: $M = 2.96$, $SD = 2.60$), $U = –2.67$, $p < .01$, focusing on student work (AE: $M = 2.60$, $SD = 2.55$; LTE: $M = 2.26$, $SD = 2.59$), $U = –2.09$, $p < .05$, and effectively supporting teaching for the redesigned AP course (AE: $M = 4.17$, $SD = 3.19$; LTE: $M = 3.52$, $SD = 2.99$), $U = –2.46$, $p < .05$, as well as using significantly more unconventional PD materials (AE: $M = 4.55$, $SD = 1.37$; LTE: $M = 4.26$, $SD = 1.34$), $U = –2.79$, $p < .01$. However, surprisingly teachers in the *better-than-expected* group rated their PD experiences regarding focus on student work ($M = 1.81$, $SD = 2.39$) significantly lower than teachers in the AE group ($M = 2.60$, $SD = 2.55$), $U = –2.46$, $p < .05$. Also, teachers in *better-than-expected* group used significantly less unconventional PD materials ($M = 4.25$, $SD = 1.17$) compared with teachers in the AE group ($M = 4.55$, $SD = 1.37$), $U = 2.19$, $p < .05$. These findings suggested that PD participation patterns varied across the three teacher groups, and they were particularly dissimilar comparing teachers with the AE group whose PD experiences exposed them with the highest dosage of "high-quality" PD characteristics. This indicated that additional factors beyond teachers' PD participation seem vital for elevating student achievement beyond their predictions, contrary to commonly held beliefs of "the more PD engagement, the better student performance."

Associations to students' AP science performance. The explorations of the teacher grouping profiles identified several distinguishing features providing some indications of what characteristics might relate to better-than-expected student performance. HLMs were applied to detect direct associations on students' performance gains (Table 7). Student-level variables (Level 1) accounted for 75% of the variance in students' performance gains, whereas 25% of the total variance in students' performance gains occurred between schools/teachers (Level 2; ICC = .25). Given that common ICC values in the social sciences range from .05 to .20 (Peugh, 2010), this ICC value justified the added value of multilevel modeling approaches compared with nested ordinary least squares multiple regressions. Most notably, each group of variables (school, teacher and teaching, and PD participation) included in the analysis significantly contributed to explain variance in students' AP performance gains (PD participation variables group was approaching significance). School context variables explained 6.40% of the variance, $\chi^2(8) = 32.47$, $p < .001$, teacher and teaching variables explained additional 6.55%, $\chi2(8) = 32.88$, $p < .001$, and the PD characteristics explained additional 2.33% of the variance in students' AP performance gains, $\chi2(8) = 14.02$, $p = 0.081$. Analyzing associations on the item level, several patterns emerged, as described below.

School-level variables. Validating findings from Research Question 1, districts' total funding allocations were significantly associated with increases in student performance gains, $b = 0.023$, $t(615) = 3.29$, $p < .01$, indicating that for every additional US$1,000 per student, students' AP performance increased by 0.023 beyond their PSAT score prediction. This finding suggested that the more financial resources were available to school, the greater the potential for students to perform better-than-expected on the AP science examinations. Also, this finding underlines the importance of sufficient funding for low-SES urban schools (and schools with urban characteristics; Biddle & Berliner, 2003). Increasing the number of days in the school year was significantly associated with an 0.013 AP performance gain for every additional 10 days of the school year, *b* = 0.013, *t*(615) = 3.30, *p* < .01, which was consistent with findings of Research Question 1 and prior research examining associations of the length of schools with student performance (Marcotte & Hansen, 2010). The lengthier the school year in low-SES urban settings, which assumes that the total hours of instructional time teaching for the AP examination increases, the greater the potential for students to perform better-than-expected on the AP science examinations. Also, this finding alluded that teachers' classroom instruction per se might influence student learning and achievement. Enforcing criteria for student enrollment in AP courses was significantly associated with an 0.094 AP performance gain, *b* = 0.094, *t*(615) = 3.02, *p* < .001. This finding suggested that restricting access to AP courses, for instance, by increasing selectivity in AP course admission and presumably creating more homogeneous structures enrolling higher percentages of more able students, improved student performance. However, enacting this practice would be contrary to current efforts to increase AP participation of all students striving to narrow opportunity gaps and increase educational equity (Conger et al., 2009; Lichten, 2010; The College Board, 2014c; Wyatt & Mattern, 2011).

Teacher-level variables. Increased knowledge and experience was significantly associated with student achievement, *b* = 0.075, *t*(615) = 3.95, *p* < .001, which validated findings of Research Question 1. Roughly a 1-standard-deviation increase in teachers' knowledge and experience composite corresponded with an 0.075 AP performance gain. This finding suggested that the higher the teachers' expertise, the greater the potential for students to perform better-than-expected on the AP science examinations. In addition, this finding underscores the importance to counteract challenges for low-SES schools to recruit highly qualified and effective teachers (Goldhaber et al., 2015; Isenberg et al., 2013).

Regarding teachers' classroom instruction, self-reported enactment of curricular elements of the AP redesign had a significant negative association with students' AP performance gain, $b = -0.042$, $t(615) = -2.52$, $p < .05$, with an 0.042 AP score penalty for about a standard deviation increase of teachers' rating on curricular enactments of the AP redesign. This counterintuitive finding suggested that the higher the teachers' self-reported enactment of AP redesign curriculum elements, the smaller the potential for students to perform better-than-expected on the AP science examinations. Potential explanations might be measurement related. Teachers' perceptions of curricular elements of the AP redesign might differ from College Board's intentions. For instance, teachers might only enact curricular elements on a surface level, thus, self-reporting high enactment while ratings by external classroom observers might be considerably lower.

PD characteristics. Each point increase in teachers' rating of a single PD activity as being supportive for teaching redesigned AP courses increased students' AP performance gains by 0.022 of an AP score, $b = 0.022$, $t(615) = 1.99$, $p < .05$. Although this PD characteristic was not explicitly included in the Desimone (2009) list of "high-quality" PD features, it is implicitly underlying all PD-related research and might be seen as a meta-PD characteristic. If teachers had not perceived PD experiences as worthy of their time and valuable for their instruction, lacking associations toward changes in teaching practice or improvements on student outcome measures would not have seemed surprising. Similarly, this finding suggested that the more teachers felt effectively supported for their AP teaching as a result of their PD experiences, the greater the potential for students to perform better-than-expected on the AP science examinations.

Table 7. Fixed-effect HLMs with robust standard errors.

AP performance gain	Model 1 *b*	Model 1 *SE*	Model 2 *b*	Model 2 *SE*	Model 3 *b*	Model 3 *SE*	Model 4 *b*	Model 4 *SE*
Level 1 (student characteristics)								
Chemistry (vs. Biology)	–0.088**	0.033	–0.090**	0.032	–0.094*	0.037	–0.104**	0.037
Parents' education level	–0.005	0.003	–0.005	0.003	–0.005	0.003	–0.006	0.003
English language proficiency	–0.138***	0.021	–0.136***	0.021	–0.137***	0.021	–0.137***	0.021
Black/African American	–0.002	0.023	–0.010	0.023	–0.003	0.023	–0.005	0.023
Asian/Asian American	0.031	0.024	0.027	0.024	0.028	0.024	0.029	0.024
Hispanic	–0.068**	0.023	–0.069**	0.023	–0.067**	0.022	–0.067**	0.022
Native	0.036	0.087	0.037	0.087	0.043	0.088	0.041	0.086
Level 2								
Intercept	0.007	0.030	–0.039	0.033	–0.043	0.058	–0.034	0.057
School characteristics								
District funding (US$1,000 increments)			0.025***	0.007	0.023**	0.007	0.023**	0.007
Days of school year (10-day increments)			0.015***	0.004	0.014***	0.004	0.013**	0.004
Charter school			–0.061	0.077	–0.064	0.074	–0.080	0.084
Administrative support			–0.001	0.015	–0.006	0.015	–0.010	0.014
AP workload			0.022	0.017	0.016	0.017	0.010	0.017
Criteria for AP enrollment			0.084**	0.032	0.088**	0.031	0.094**	0.031
Teacher and teaching characteristics								
Female (vs. male)					0.024	0.036	0.019	0.037
Disciplinary major					–0.017	0.042	–0.025	0.042
Knowledge and experience					0.076***	0.019	0.075***	0.019
PD inclination					–0.023	0.016	–0.023	0.016
Number of labs					–0.004	0.004	–0.003	0.004
Challenges with the AP redesign					–0.026	0.015	–0.026	0.015
Enactment: AP practices					0.020	0.014	0.019	0.014
Enactment: AP curriculum					–0.040*	0.016	–0.042*	0.016
PD characteristics								
Active learning							–0.018	0.010
Responsive agenda							0.014	0.011
Focus on student work							–0.007	0.011
Modeling teaching							–0.015	0.013
Building relationships							–0.015	0.010
Effective support							0.022*	0.011
Unconventional PD: F2F							0.041*	0.021
Unconventional PD: Materials							–0.007	0.012
Level 2 variance	0.1336		0.1248		0.1157		0.1125	
Explained variance (Level 2; %)	3.38		9.78		16.33		18.66	
χ^2	87.19		32.47		32.88		14.02	
p value	<.001		<.001		<.001		0.081	

Note. White was the reference for the race/ethnicity variables; continuous variables were grand mean centered. HLM = hierarchical linear model; *$p < .05$. **$p < .01$. ***$p < .001$.

Each participation in unconventional face-to-face PD activities was associated with a 0.041 AP performance gain, $b = 0.041$, $t(615) = 1.98$, $p < .05$. This finding suggested that the more often teachers participated in teacher-initiated meetings, mentoring activities, or conferences, the greater the potential for students to perform better-than-expected on the AP science examinations. Commonalities of these PD activities include its highly collaborative and informal character in which teachers might broaden and deepen their professional networks.

In general, finding direct associations of teachers' PD participation on student achievement is somewhat unexpected because this relationship is mediated by changes in teachers' knowledge and skills and shifts in instructional practices (Desimone, 2009). Also, the strength of these associations is stronger than expected. For example, teachers' participation in two unconventional face-to-face PD activities and in two 1-day conventional PD activities, which were self-reported as maximally effective for supporting AP teaching, corresponded with an average 0.258 student AP performance gain. Being able to detect such direct associations for teachers in low-SES urban schools (or schools with urban characteristics) emphasizes the potential of purposefully selected PD activities to narrow opportunity gaps and to improve student learning and achievement.

Limitations and future work. The main limitations of this study were related to the nature of the data source and the applied statistical methods. The major threat to internal validity was that teacher-level data were limited to teachers' self-reports to the web-based surveys. Given the nationwide scope and scale of this project, collecting additional triangulation data, such as classroom observations of teachers' instruction, was not feasible. Threats to external validity were that student identifiers were unique for AP Biology and AP Chemistry, creating the possibility that students taking the AP Biology and AP Chemistry examinations were treated as two separate cases yielding oversampling and a selection bias. However, this bias should be small, given typical science course-taking patterns in high school. Also, with the absence of student–teacher identifiers, student-level data were tied to school-level data. Hence, teachers associated with two or more schools and multiple AP teachers who taught the same AP subject in the same school were removed from the analysis. Future research will evaluate the relevance of this constraint by exploring similarities and differences of school, teacher, teaching, and PD participation characteristics when there are solo versus multiple AP science teachers in a subject.

Methodologically, HLM assumes linear relationships between independent and dependent variables detecting direct effects. However, some relations might be better described through polynomial, exponential, or other relationships. In addition, interaction, mediating, and moderating effects might occur, indicating that independent variables might have indirect, dynamic relationships toward student achievement. Therefore, future studies could extend this research through multilevel structural equation models and path analyses to explore such indirect effects.

Discussion

Scholarly significance. As a large-scale, quantitative study (638 teachers, 11,800 students), with a good nationwide representation of the AP science teacher population in low-SES urban schools (and schools with urban characteristics), this study offers a unique contribution to the research base on student achievement. The mandated top-down curriculum and assessment changes to the revised AP science courses and examinations constituted a unique opportunity for research into student achievement related to these large-scale changes and how that achievement is shaped by associations with school, teacher, teaching, and PD participation characteristics. Insights into factors that increase student performance in urban schools (and schools with urban characteristics) beyond predicted scores may generalize to other nationwide educational assessment and curriculum reforms, such as the NGSS or the Common Core State Standards Initiative. To the best of the authors' knowledge, this is the first large-scale study that analyzes associations toward student achievement in low-SES urban schools (and schools with urban characteristics) at an early implementation stage of a nationwide science curriculum reform.

Also, the approach of evaluating students' actual achievement in correspondence with their predicted performance represents an advancement in existing research. This novel approach allows us to simultaneously account for both students' current and prior achievement, for instance, aiding classifications of student performance-based teacher groups. Thus, interpretations of student outcome measures can be shifted toward identifying "what works" to aid students to perform better-than-expected on the high-stakes AP science examinations.

Implications and conclusion. This study attempts to provide guidance to inform educational policy makers' and school leaders' decision-making processes for narrowing opportunity and income achievement gaps, and fostering educational equity, especially within low-SES urban schools (and schools with urban characteristics). The three main conclusions from this study are as follows:

First, school context matters. This has long been known, of course, but seeing how context matters in relation to a specific high-stakes exam with critical implications for college course-taking is an extension of prior literature in this area (e.g., Roegman & Hatch, 2016). Districts' per-student total funding allocations and the length of the school year have positive significant associations with students' AP performance gains. Therefore, increasing district's total expenditures per student as well as the length of instruction for teaching AP science in low-SES urban schools (and schools with urban characteristics) could be further explored. Furthermore, to the best of the authors' knowledge, this is the first study that analyzed influences of districts' funding allocations and school year lengths on students' AP science performance.

Second, teachers make a difference. Teachers' knowledge and experience had positive significant associations with students' AP performance gains. Therefore, incentivizing experienced and skilled teachers to be recruited and retained within low-SES urban schools (and schools with urban characteristics) should be further explored. This is one of the few studies that directly relates teachers' knowledge and experience in low-SES schools to student achievement strengthening prior research that stated the need for disadvantaged students to have equitable access to highly qualified teachers (e.g., Isenberg et al., 2013).

Third, PD can help teachers improve student achievement but only in particular circumstances. Participation in PD activities that teachers rated as effective for helping them teach redesigned AP science courses and participation in unconventional face-to-face PD activities such as teacher-initiated meetings, mentoring or coaching activities, and conference participations were positively and significantly associated with students' AP performance gains. Therefore, guiding teachers in low-SES urban schools (and schools with urban characteristics) to purposefully select their PD participations could be further explored. Our data also reinforce findings that PD needs to be coherent with respect to what teachers are asked to do in the classroom (Penuel et al., 2007). When teachers indicated that PD was effective in helping them with core features of AP instruction, their students performed better.

The guiding vision of this study ultimately aims for changes in the educational landscape to narrow opportunity gaps and increase overall student learning and achievement. Our data suggest that teacher participation in purposefully selected PD activities, in alignment with proactive educational policies increasing school funding, days of instruction, and teacher quality, can make a difference in the challenge of assisting students in low-SES urban schools to succeed on their path through the U.S. education system.

Chapter Three – Investigating relationships between school context, teacher professional development, teaching practices, and student achievement in response to a nationwide science curriculum and assessment reform

Abstract

This large-scale, quantitative study analyzes relationships among school context, teachers' professional development (PD) participation, teacher knowledge, instructional practices, and student achievement in response to the Advanced Placement curriculum and examination reform in the sciences. The study is based on data from 133,336 students and 7,434 teachers. Multi-level structural equation models indicate that teachers' PD participation and perceived challenges with the curriculum reform significantly influence instructional elements related to the curriculum reform. In turn, aspects of instructional enactments and student-context characteristics are significantly associated with student performance. However, association of instruction with student performance are very weak. In general, this study validates elements of Desimone's (2009) conceptual framework on teacher PD and suggests to advance research that identifies effective instructional practices.

Keywords: Science education, curriculum reform, professional development, instructional practice, high-stakes testing, Advanced Placement

In times of changing curricular standards induced through large-scale curricular reforms such as the Common Core State Standards Initiative (2010a, 2010b) or the Next Generation

Science Standards (NGSS; NGSS Lead States, 2013), it is critical to prepare teachers for the challenge to adequately align their teaching to new educational landscapes. Desimone's (2009) logic model for studying the effects of professional development (PD) describes that teachers' PD participation is associated with knowledge and skill gains that relate to changes in instructional practice, which in turn lead to increased student learning and achievement. While this conceptual framework is widely accepted and adopted in the field, validation studies indicate mixed empirical evidence and call for more research to better understand how teacher PD translates into effective practice (Desimone & Garet, 2015). This study responds to this call for research by examining how teachers adapt to the redesign of the Advanced Placement (AP) program in the sciences from a perspective of Desimone's (2009) framework.

College Board, the provider of the AP examinations, responded to the recommendations of the National Research Council (2002) and revised the AP program in an attempt to increase student learning and preparation for study beyond high school. The AP program provides opportunities for high school students to engage in rigorous, college-level courses in a broad range of subject areas. Students often regard AP examinations as high-stakes because of perceived benefits for college admission and the potential to count passing scores toward college credit or placement in more advanced disciplinary courses. The revised AP curriculum reduces its former emphasis on broad content coverage and prescribed algorithmic procedures. In turn, the emphasis on scientific practices, critical thinking, inquiry, and depth of understanding of science concepts is increased. These changes are in line with the Framework for K-12 Science Education (National Research Council, 2012a) and the NGSS (NGSS Lead States, 2013). Teachers have strong incentives to engage in PD activities to align their instruction with the new AP program in order to properly prepare their students for the revised AP examinations. Hence, this large-scale, top-down, nationwide curriculum reform constitutes an excellent opportunity to validate elements of Desimone's (2009) framework.

Conceptual framework

Situated within the context of College Board's AP science redesign, this study attempts to contribute to the in-service secondary science teacher education research base by investigating selected aspects of the relationships described in Desimone's (2009) framework for studying the effects of PD (Figure 3). The arrows in Figure 3 illustrate the foci of this study analyzing associations of teachers' PD participation with teachers' instruction (research question 1), as well as associations of teachers' instruction with student achievement (research question 2), situated in the corresponding local contexts. The greyed out elements in Figure 3 (i.e., teacher knowledge and skills box, arrows between boxes) illustrate elements of the framework not part of this study.

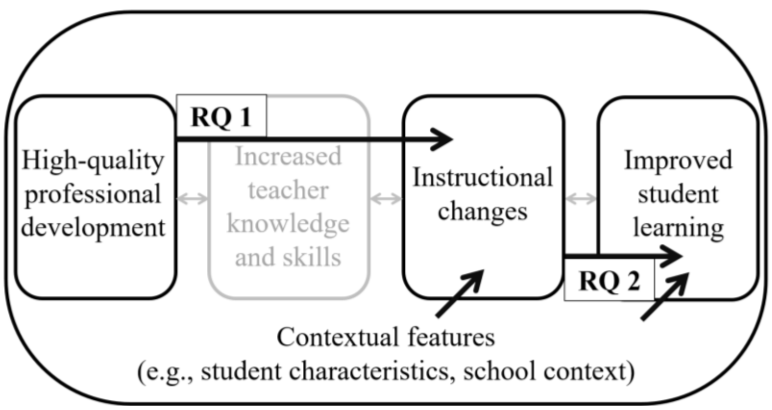

Figure 3. Situating the study within Desimone's (2009) framework.

Importance and impact of PD participation. As described in Desimone's (2009) framework, the most direct outcomes of teachers' participation in effective PD activities are increases in teacher knowledge and changes in teachers' beliefs which might indirectly enable teachers to modify their classroom instruction.

Characteristics of effective PD activities. In past decades many studies evaluated the impact of professional learning activities to discern characteristics of effective PD for teachers. Desimone (2009) summarizes this research base and identifies active learning, coherence, content focus, collective participation, and duration as core features of high-quality PD. Active learning refers to PD that affords opportunities for teachers to actively contribute to the knowledge and skills building process through activities such as interactive feedback on teaching demonstrations or review of student work. Coherence refers to PD that is connected to existing curriculum implementations, standards, and policies, as well as teachers' prior knowledge, skills, and beliefs. Content focus refers to PD that increases teachers' expertise related to different knowledge domains of teaching. Collective participation refers to affordances of PD activities that enable participation from teachers in similar local contexts such as teachers from the same grade-level, disciplinary concentration, or school. Duration refers to both the total contact time and frequency of teachers' interactions with the PD environment. Notably, this list of design features is similar to other listings of characteristics that constitute high-quality PD. For instance, Borko et al. (2010) emphasize the importance for PD design to situate content in practice, focus on student learning, model teaching practices, afford active learning, help create collaborative professional learning communities, align goals to school settings, and provide on-going and sustainable learning opportunities. Similarly, Darling-Hammond, Hyler, and Gardner (2017) highlight that the design of effective PD include a focus on content, incorporation of active learning, support of collaboration, use of models of effective practice, opportunities for coaching and expert support, offers for feedback and reflection, and a sustained duration. Nevertheless, design features of PD activities only represent one aspect that might contribute to effective PD participation. For instance, Kennedy's (2016) review of 28 studies on the influence of PD on instructional practices concludes that PD effectiveness highly varies, even for PD with similar design characteristics. Kennedy (2016) indicates that PD effectiveness also depends on factors such as the PD program's underlying pedagogy to promote teacher learning. Other influences on PD effectiveness might include teachers' motivation to engage in PD, teachers' micro-level interactions during their PD engagement, and local school context factors (Desimone & Garet, 2015; Kennedy, 2016).

Influence of PD participation on teachers' knowledge and instruction. Numerous research studies indicate that participation in PD that has a focus on content, provides coherent learning experiences, models instructional enactments, affords collective participation, or has high duration are associated with increases in teacher knowledge (C. D. Allen & Penuel, 2015; Banilower et al., 2007; Fishman et al., 2013; Garet et al., 2001; Heck, Banilower, Weiss, & Rosenberg, 2008; Penuel et al., 2007; Roth et al., 2011). For instance, the study of Roth et al. (2011) on PD programs that use video-based science lesson analyses finds associations of PD participation with increases in both teachers' content knowledge and teachers' ability to reflect on instruction. Similarly, Fishman et al. (2013) analyze a broad range of PD offerings and indicate that PD participation relates to increases in teachers' self-efficacy. Besides more formal PD activities, teacher participation in informal learning activities such as museum visits, collaboration with colleagues, or peer-mentoring also possess potential to increase teachers' knowledge and skills (Jackson, Rockoff, & Staiger, 2014; Kyndt, Gijbels, Grosemans, & Donche, 2016; Melber & Cox-Petersen, 2005). For instance, the systematic review of 74 studies of Kyndt et al. (2016) emphasizes the importance of informal learning for teacher knowledge gains, in particular in the context of reforms or innovations.

Studies that explore direct associations of teachers' PD participation on the enactment of instructional practices find that PD that focuses on content, provides opportunities for collaborative or collective participation, ensures coherence with local contexts, includes active learning, or offers sustained and frequent exposure to professional learning lead to changes of teachers' classroom instruction (Banilower et al., 2007; D. K. Cohen & H. C. Hill, 2000; Correnti, 2007; Fishman et al., 2013, 2003; Garet et al., 2001; Heck et al., 2008; Jeanpierre, Oberhauser, & Freeman, 2005; Matsumura, Garnier, & Resnick, 2010; Penuel et al., 2007; Roth et al., 2011; Supovitz & Turner, 2000). For instance, the study of Jeanpierre et al. (2005) indicates that emphases on science content, as well as opportunities to connect procedural knowledge to practice, lead to increased implementations of inquiry-based instruction in teachers' classrooms.

Factors related to student learning. At the heart of every curriculum reform and PD activity is the desire to ultimately advance student learning. However, as indicated in Desimone's (2009) framework, relationships of PD participation and student achievement are indirect and mediated by teachers' knowledge and instructional practices. Teachers' classroom instruction can be seen as the most direct teacher-level influence on student learning. Besides teacher-level factors, student background and the local school characteristics also influence student learning.

Influence of PD participation. Although the influence of teachers' PD participation on student learning is mediated by numerous factors, several research studies were able to detect direct effects of PD on student achievement (D. K. Cohen & Hill, 2000; Fischer, Fishman, et al., 2016; Fishman et al., 2013, 2003; Lee, Deaktor, Enders, & Lambert, 2008; Penuel, Gallagher, & Moorthy, 2011; Roth et al., 2011; Saxe, Gearhart, & Nasir, 2001). For instance, the study of Penuel et al. (2011) on different PD programs for secondary science teachers indicate that PD programs that emphasize modeling of teaching are associated with increases in student learning. Similarly, the study of Fischer, Fishman et al. (2016) on adoption patterns to the AP science redesign in low-SES schools (which utilizes the same data sources used in this study) indicates that teacher participation in unconventional PD activities and PD that teachers perceive to effectively support their instruction are significantly associated with student performance gains.

Influence of teacher and teaching characteristics. A large array of research studies indicate that large variations in teacher quality are associated with differences in student achievement (Aaronson, Barrow, & Sander, 2007; Jackson et al., 2014; Kane & Staiger, 2008; Rivkin, Hanushek, & Kain, 2005; Rockoff, 2004; S. P. Wright, Horn, & Sander, 1997). Notably, the focus of these studies is not to analyze direct effects of classroom instruction with student performance but to identify teacher characteristics associated with increased student performance. Such teacher characteristics are likely to moderate the effectiveness of teachers' instruction (D. K. Cohen & Ball, 1999; Supovitz & Turner, 2000). For instance, teachers' content knowledge is often viewed as an important predictor for student performance (H. C. Hill, Rowan, & Ball, 2005; Ma, 2010). Other studies detect direct effects of teachers' years of teaching experience with student achievement (Boyd, Lankford, Loeb, Rockoff, & Wyckoff, 2008; Kraft & Papay, 2014; Nye et al., 2004; Papay & Kraft, 2015; Wiswall, 2013). Other important teacher-level influences include teachers' attitudes and beliefs. For instance, Klassen and Tzes' (2014) meta-analysis of 43 studies on psychological teacher characteristics indicates that teachers' self-efficacy is significantly associated with student performance.

The impact of teachers' classroom instruction on student learning and achievement is validated in many research studies and research syntheses (e.g., Hattie, 2009, 2012, National Research Council, 2005, 2012b). For instance, research studies in the context of mathematics and science curriculum reforms indicate that teachers' enactments of reform- or inquiry-oriented instructional elements are significantly associated with increases in students' performance (Hamilton et al., 2003; Secker, 2002). Similarly, Desimone, Smith, and Phillips' (2013) study finds stronger student achievement gains for teachers who emphasize more advanced topics compared to more procedural skills.

Student characteristics. Students' individual background traits have a substantial influence on student learning and performance. Prior knowledge is often viewed as an important predictor of student achievement. In the context of the AP program, prior research validated associations between students' performance on the Preliminary Scholastic Aptitude Test (PSAT) and the AP examinations (Ewing et al., 2006; Ewing, Huff, & Kaliski, 2010; Zhang, Patel, & Ewing, 2014). However, this relationship can in part be explained by students' socioeconomic status (SES) (Atkinson & Geiser, 2009; Rothstein, 2004). For instance, an analysis of student performance on PISA benchmark assessments estimates that 15% of the variance in student scores is explained by student-level socioeconomic factors. Such factors include family wealth and income, parental educational attainment and occupation, and neighborhood and school resources, among others (National Center for Education Statistics, 2012). For instance, Davis-Keans' (2005) secondary data analysis of a national cross-sectional data base finds indirect associations of parental educational attainment and family income on student achievement.

Local school contexts. While it is tempting to attribute teaching quality and student achievement gains in large parts to teacher quality, Kennedy (2010) cautions that contextual factors outside of teachers' control can influence instruction. Supportive educational leadership is related to participation in professional learning opportunities, changes in instructional practices, and increases in teacher effectiveness and student achievement (Banilower et al., 2007;

Heck et al., 2008; Johnson, Kraft, & Papay, 2012; Kraft & Papay, 2014; Ladd, 2009; Leithwood, Seashore, Anderson, & Wahlstrom, 2004; May & Supovitz, 2011). For instance, a study by Supovitz, Sirinides, and May (2010) in the context of a midsized urban district indicates that both peer influence (e.g., conversations with peers about instruction, seeking and providing assistance regarding instructional topics) and principal leadership (e.g., trusted teacher-principal relationships, principal focuses leadership on instruction) are indirectly associated with increased student learning. Also, Coburn, Russell, Kaufman, and Steins' (2012) indicate that teachers with a strong social network that includes teachers with deep content expertise and teachers who they frequently interact with demonstrate more sustained instructional improvement related to curriculum reforms. Additionally, time allotted for course preparation and course instruction, continuous assignments to teach courses in similar grade levels, and collaboration with and support from other teachers in the school are associated with teachers' instruction and student achievement (Kennedy, 2010; Kyndt et al., 2016; Ladd, 2009; Ost, 2014; Supovitz et al., 2010). Furthermore, school affluence, which is often estimated with measures that describe the availability of resources for classroom instruction, school or district funding, and crime rates, is related to teaching quality and student performance (Sass, Hannaway, Xu, Figlio, & Feng, 2012; Steinberg, Allensworth, & Johnson, 2011; Supovitz & Turner, 2000).

Research questions

This study responds to the call for research by Desimone and Garet (2015) to validate Desimone's (2009) framework by analyzing how PD can translate into changes in instructional practice that relates to increased student performance. The research questions of this study are aligned with the study of Desimone et al. (2013), which is similar in scope and also uses

Desimone's (2009) framework. The research questions that this study examines are the following:

Research Question 1: What are the relationships among teacher professional development, teacher characteristics, and school characteristics on teachers' self-reported instructional practices?

Research Question 2: What are the relationships among teachers' self-reported instructional practices, school context, and student characteristics on students' performance on the AP science examinations?

From a PD perspective, the first research question assumes an indirect (and not measured) effect of increases in teachers' knowledge and skills induced through teachers' PD participation (Figure 3). The second research question can be viewed as an implicit analysis of the distant effects of teachers' PD participation on student achievement on the AP exams mediated by teachers' classroom instruction (Figure 3). Both research questions are answered using the same statistical modeling framework to account for such implicit relationships.

Methods

Data sources and sample. This study is connected to a longitudinal National Science Foundation-funded research project. The goals of the larger project are to better understand teachers' PD adoption patterns and their relations to student achievement in response to the AP examination and curriculum reform in the sciences. The data in this study comes from two sources. First, student- and school-level data for all students taking redesigned AP science examinations is provided from the College Board. Student-level data includes student achievement data (i.e., AP and PSAT scores), as well as student family background characteristics (i.e., parental educational attainment). School-level data includes information on the enrollment in the school and in free- or reduced-priced lunch programs. Second, teacher-level information is collected through web-based surveys to all AP Biology, AP Chemistry, and AP Physics in the United States, unless teachers opted out of College Board's official communication. The surveys inquire about PD participation (e.g., quantity and quality of PD), teaching background (e.g., years of teaching experience), school context (e.g., principal support, length of instruction), classroom instruction (e.g., enactment of labs, enactment of AP practices), and concerns (e.g., perceived challenges with AP redesign). Prior to the first administration of the surveys a panel of experts with PD, science education, and measurement expertise critiqued survey pilots. Additionally, survey items were validated with a cognitive interview approach (Desimone & Le Floch, 2004). Survey reliability is tested through comparisons of survey response distributions across survey disciplines and years.

Table 8. Descriptions of analytical samples.

	Biology Year 2	Biology Year 3	Chemistry Year 1	Chemistry Year 2	Physics Year 1
N – Student-level	29,632	25,195	30,740	24,993	22,776
N – Teacher/School-level	1,544	1,530	1,770	1,518	1,072

This study uses data related to the 2014 (AP Biology and AP Chemistry) and 2015 (AP Biology, AP Chemistry, and AP Physics) AP science examinations. Table 8 describes the samples sizes after list-wise deletion of observations with missing data. These samples are called "analytical samples." Mann-Whitney U tests compare the analytical samples with comparison samples that include all other students/schools in the schools to estimate the generalizability of the samples (Table 9). The analyses indicate that students in the analytical samples perform slightly better than the comparison group on the AP examinations (Biology Year 2: $z = 31.55$, $p < 0.001$, $r = 0.071$; Biology Year 3: $z = 27.70$, $p < 0.001$, $r = 0.061$; Chemistry Year 1:

$z = 32.42$, $p < 0.001$, $r = 0.091$; Chemistry Year 2: $z = 20.86$, $p < 0.001$, $r = 0.056$; Physics Year 1: $z = 14.95$, $p < 0.001$, $r = 0.038$) and the PSAT examinations (Biology Year 2: $z = 10.48$, $p < 0.001$, $r = 0.026$; Biology Year 3: $z = 8.06$, $p < 0.001$, $r = 0.020$; Chemistry Year 1: $z = 6.56$, $p < 0.001$, $r = 0.020$; Chemistry Year 2: $z = 20.86$, $p < 0.001$, $r = 0.056$; Physics Year 1: $z = 2.25$, $p < 0.05$, $r = 0.006$). Also, the schools of students in the analytical samples have a slightly lower percentage of enrollment in free- or reduced-priced lunch programs than schools in the comparison group (Biology Year 2: $z = 5.93$, $p < 0.001$, $r = 0.065$; Biology Year 3: $z = 5.23$, $p < 0.001$, $r = 0.057$; Chemistry Year 1: $z = 5.61$, $p < 0.001$, $r = 0.071$; Chemistry Year 2: $z = 5.69$, $p < 0.001$, $r = 0.069$; Physics Year 1: $z = 2.80$, $p < 0.01$, $r = 0.042$). All differences between analytical samples and comparison groups are below a 0.1 effect size threshold, constituting a small effect (J. Cohen, 1992; Ferguson, 2009). Therefore, the analytical samples can be viewed as a good representation of the overall AP science population in the United States in the corresponding years and disciplines.

Measures. ***Student-level measures.*** The student-level variables in the analysis include students' examination scores on the redesigned AP Biology, AP Chemistry, and AP Physics 1 examinations. These variables are used as continuous dependent variables in the corresponding models and represent the main student-level outcome of interest. Students' prior achievement is treated as a continuous variable and measured through students' PSAT scores as previous research indicates strong correlation of PSAT scores with students' performance on AP examinations (e.g., Ewing et al., 2006). Mothers' educational attainment is included in the models to describes students' family background, which is assumed to be related to student learning (e.g., Davis-Kean, 2005; Desforges & Abouchaar, 2003; Woessmann, 2004). This ordinal variable distinguishes educational attainment in the categories *no post-secondary* *education*, *some post-secondary education* (including Associate degrees), *Bachelor's degree*, and *graduate degree* (including doctoral and professional degrees).

Table 9. Descriptive information of non-response analysis.

	N	Mean	SD	N	Mean	SD
		AP scores			*PSAT scores*	
Biology Y2 (in sample)	29,632	3.09	1.02	29,632	166.64	26.82
Biology Y2 (comparison)	168,966	2.88	1.05	132,080	164.88	27.55
Biology Y3 (in sample)	25,195	3.08	1.00	25,195	165.47	26.58
Biology Y3 (comparison)	183,785	2.88	1.03	145,137	163.99	27.61
Chemistry Y1 (in sample)	30,740	2.86	1.23	30,740	174.59	26.43
Chemistry Y1 (comparison)	97,350	2.60	1.25	78,278	173.32	27.08
Chemistry Y2 (in sample)	24,993	2.78	1.21	24,993	173.78	26.63
Chemistry Y2 (comparison)	111,940	2.60	1.23	92,395	173.20	27.69
Physics 1 Y1 (in sample)	22,776	2.37	1.18	22,776	168.86	26.27
Physics 1 Y1 (comparison)	129,489	2.25	1.15	108,353	168.37	27.16
Percentage free- or reduced-priced lunch program						
Biology Y2 (in sample)	1,544	26.16%	24.20%			
Biology Y2 (comparison)	6,689	30.66%	26.16%			
Biology Y3 (in sample)	1,530	29.09%	25.64%			
Biology Y3 (comparison)	6,959	33.12%	26.93%			
Chemistry Y1 (in sample)	1,770	24.73%	23.37%			
Chemistry Y1 (comparison)	4,502	28.78%	25.19%			
Chemistry Y2 (in sample)	1,518	26.77%	24.19%			
Chemistry Y2 (comparison)	5,198	31.15%	25.84%			
Physics 1 Y1 (in sample)	1,072	29.30%	24.58%			
Physics 1 Y1 (comparison)	3,349	32.03%	25.77%			

School-context measures. School-context variables include a continuous variable that describes SES as measured by the school-level percentage of students enrolled in free- or reduced-priced lunch programs. Similar to parental education attainment, lunch program enrollment is often used to describe poverty measures (National Center for Education Statistics, 2011, 2012) and the relations of SES with student achievement are well documented (e.g., OECD, 2013a; Sass et al., 2012; Supovitz & Turner, 2000). Additionally, a continuous composite variable that describes teachers' perceived administrative support (i.e., principal understands the challenges for AP science students, principal understand challenges for AP science teachers, principal support PD participations, lighter teaching loads for AP teachers, fewer out-of-class responsibilities for AP teachers, additional funding for AP science, availability of equipment to perform labs, and availability of expendable supplies to perform labs) is included in the models, as supportive school environments are often found to improve teachers' educational effectiveness (Kraft & Papay, 2014; Ladd, 2009; Waters, Marzano, & McNulty, 2003).

Teacher characteristics measures. The teacher characteristics variables in the models include teachers' years of AP teaching experience and years of AP redesign experience in the corresponding science discipline. Previous research indicates that teaching experience is an important factor for increasing teacher effectiveness and student learning (Boyd et al., 2008; Kraft & Papay, 2014; Papay & Kraft, 2015; Wiswall, 2013), especially if the accumulated teaching experience is closely related to current instructional assignments (Ost, 2014). Additionally, a continuous composite variable that describes teachers' self-reported challenges with the AP redesign (i.e., teachers feel challenged with science content, organization of science content, laboratory investigations, inquiry laboratory investigations, format of questions/problems/AP examination, application of science practices, development of new syllabi, "exclusion statements," design of new student assessments, use of the textbook, pacing of the course, and facilitation of conceptual understandings of science).

Instructional practice measures. Teachers' classroom teaching is described with a continuous variable describing teachers' self-reported number of laboratory investigations and a continuous composite variable that describes teachers' enactment of practice elements related to the AP redesign (i.e., provide guidance on integrated content, provide guidance on open and free response questions, enable students to report laboratory findings to one another, have students perform laboratory investigations, and have students perform inquiry laboratory investigations).

Laboratory investigations are often viewed as important for high school science courses and the AP science curriculum redesign further emphasizes the importance of labs to promote inquiry learning (e.g., Magrogan, 2014; National Research Council, 2006; Price & Kugel, 2014). Similarly, research indicates that changes in instructional enactments aligned with more ambitious curricular goals such as inquiry or reform-based instruction are related with improved student performance (e.g., Hamilton et al., 2003; Secker, 2002). Furthermore, the models include a continuous variable that describes the total hours of AP science course instruction, as exposure to instruction is often assumed to be associated with student performance (Marcotte & Hansen, 2010).

Professional development measures. Teachers' PD participation is described with continuous variables that evaluate both quantity and quality of teachers' PD engagement. The variables that measure quantitative aspects of teachers' PD participation describe the number of teachers' self-reported participations in conventional and unconventional PD activities (Table 10). The variables that measure qualitative aspects of teachers' PD participation are inspired by frameworks of design features for high-quality PD activities and describe the degree in which teachers' overall PD exposure includes elements of active learning, has an agenda responsive to teachers' needs and interests, models teaching, has a focus on student work, offers opportunities to build relationships with colleagues, and effectively supports teaching redesigned AP science courses. Teachers self-reported the quality of each conventional PD activity they participated in on each of these PD features on a 5-point Likert scale (0-4). This rating is multiplied by a duration factor (1 = low duration [≤ 8 hours]; 2 = moderate duration [8-40 hours]; 3 = high duration [> 40 hours]) and summed up across all conventional PD activities a teacher participated in to create overall "exposure" measures. Numerous research studies relate teachers'

PD participation with increases in teachers' knowledge and skills and changes in teaching practices (e.g., Banilower et al., 2007; Fishman et al., 2013; Penuel et al., 2011; Roth et al., 2011).

Table 10. List of PD options included in surveys.

Conventional PD activities	*Face-to-face*: AP Summer Institute[CB], AP Fall Workshop[CB], Transition to inquiry-based labs workshop[CB], Day with AP reader[CB], Laying the foundation by NMSI, BSCS Leadership Academy by BSCS and NABT, Reasoning skills workshop[CB] *Online courses*: Transition to inquiry labs[CB], Introduction to AP Biology/Chemistry/Physics[CB], AP Central webcast – Exploring atomic structure using photoelectron spectroscopy[CB], AP insight[CB] *Online communities*: AP online teacher community[CB], NSTA online teacher community
Unconventional PD activities	*Face-to-face*: District/regional/local college/teacher-initiated meetings, mentoring/coaching one-on-one or with other teachers, conference or conference sessions, Serving as AP exam reader, Serving as AP consultant *Materials*: AP course and exam description[CB], AP lab manual[CB], teacher textbook guide and related materials, student guide – data analysis[CB], teacher guide – quantitative skills and analysis[CB], AP practice exams, materials developed from colleagues, articles from magazines or journals, video resources, computer-based simulations

Note. [CB]: PD was provided by the College Board; the lists of PD activities on the web-based surveys differ by discipline and survey year.

Analytical methods. Prior to the exploration of the research questions, data preparation strategies are applied separately for each discipline and year. The composite variables that describe teachers' perceived administrative support, challenges with the AP redesign, and enactment of AP practice elements use the full sample of teachers responding to the web-based surveys. These composite variables are computed with Bartlett factor scores derived from initial exploratory and confirmation factor analysis approaches. PD participation patterns composite variables are computed through summation and scalar multiplication operations on teachers' responses to Likert-scale items as described in Fischer, Fishman, et al. (2016). Table 11 lists all variables and describes whether variables are grand-mean centered and z-score transformed in the analyses.

Table 11. List of variables included in analysis.

Level 1
Student characteristics
AP scores[†]
PSAT scores[†,‡]
Mothers' educational attainment [D]
Level 2
School characteristics
Percentage of students enrolled in free- or reduced-priced lunch programs[†]
Administrative support[†,‡]
Teaching characteristics
Hours of AP science instruction[†]
Number of laboratory investigations[†]
Enactment of AP science practice elements[†,‡]
Teacher characteristics
Years of AP redesign experience[†]
Years of AP teaching experience[†]
Challenges with the AP redesign[†,‡]
PD characteristics
PD includes active learning[†,‡]
PD has responsive agenda[†,‡]
PD models teaching[†,‡]
PD focuses on student work[†,‡]
PD helps relationship building[†,‡]
PD effectively supports instruction[†,‡]
Number of conventional PD participations[†]
Number of unconventional PD participations[†]

Note. [†]: Grand-mean centered, [‡]: z-score transformed, [D]: Series of dummy variables.

The analysis applies multi-level structural equation modeling with students (level 1) nested within teachers/schools (level 2) (Hoyle, 2012; Rabe-Hesketh et al., 2004, 2007). Teacher- and school-level variables are included on the same level due to the absence of student-teacher identifiers. Students can only be linked to their school. Therefore, schools with more than one AP science teacher in the corresponding discipline are removed from the analytical sample in order to uniquely match students with teachers. Model building of the structural equation models is guided by both conceptual and statistical considerations. Figure 4 describes the path diagram of the final structural equation models. From a conceptual perspective, variables are selected with respect to the literature base. Also, the models are built to be consistent across disciplines and years. From a statistical perspective, the model optimization processes utilize modification indices, and other strategies, to improve the model fit. Model fit is assessed by goodness-of-fit indices including the Tucker-Lewis index (TLI), comparative fit index (CFI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR). The model fit of the final models is substantially better than commonly described threshold values; TLI ≥ 0.95, CFI ≥ 0.95, RMSEA ≤ 0.06, SRMR ≤ 0.08 (Schreiber, Nora, Stage, Barlow, & King, 2006).

Limitations. Limitations of this study relate to the nature of the data sources. The major threat to external validity is the absence of student-teacher identifiers such that student-level data is tied to school-level data. In order to uniquely match students to teachers, only schools with one teacher in the corresponding discipline are included in the analytical samples. However, the non-response analysis indicates that the influence of this threat is minimal. Therefore, the results of the analysis can be interpreted as representative for the AP science teacher population. Notably, AP teachers and students are often considered high achievers which might limit inferences to the overall student and teacher populations in the United States. Threats to internal validity include that data that more explicitly assesses teachers' knowledge is not collected. The substitute construct, teachers' perceived challenges with the AP redesign, might foreground a slightly different concept. The major threat to objectivity is that instructional practice measures are based on teachers' self-reports. While similar studies also rely on self-reported data (Banilower et al., 2007; Garet et al., 2001; Supovitz & Turner, 2000), its validity and reliability remain unclear (e.g., Desimone, Smith, & Frisvold, 2010). However, given the national scope of this project, the collection of additional classroom observation data was not feasible.

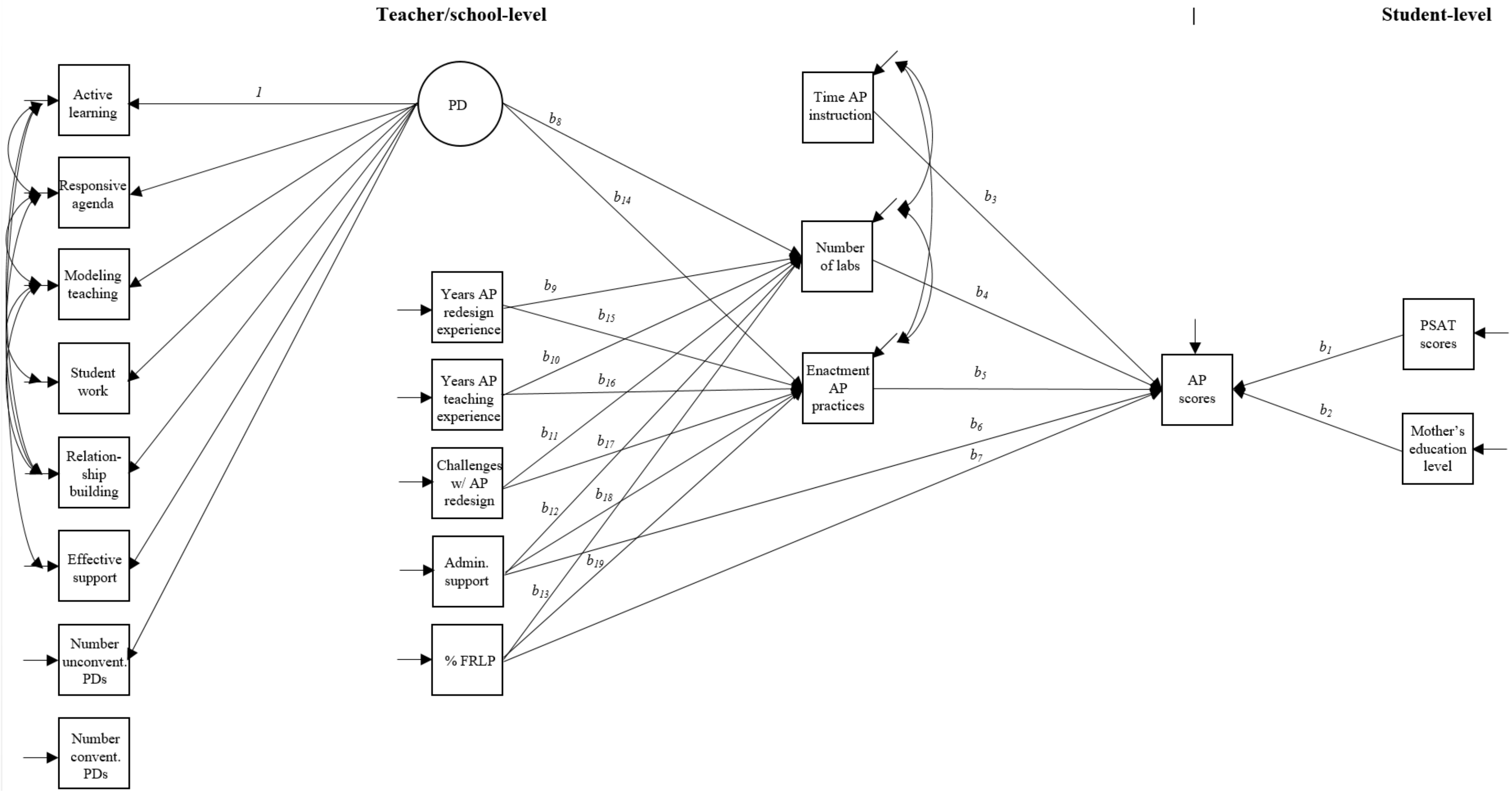

Figure 4. Model of the relations of teachers' school context, PD participation, instructional enactments, and student performance.

From a methodological perspective, limitations of the multi-level structural equation models include that only linear relationships are modeled. Some relationships might be better described with polynomial, exponential, or other relationships. For instance, previous research indicates that the influences of the years of teaching experience are stronger in the first years of teaching compared to later years in a teaching career (Boyd et al., 2008; Wiswall, 2013). Additionally, in order to follow the sequential logic of Desimone's (2009) framework for studying the effects of PD, the analysis follows what Opfer and Pedder (2011) describe as "process-product logic" (p. 384). From a complexity theory perspective, processes in the educational system are more likely to constitute interdependent, dynamic, and multidimensional relationships (Cochran-Smith et al., 2014) such that the used methodology might oversimplify existing real-life processes. Furthermore, in the attempt to increase consistency across models for all disciplines and years, the model fit for individual models is slightly lower compared to hypothetical models that do not adhere to this consistency principle. Nonetheless, all models in the analysis fulfill recommended model fit thresholds (Schreiber et al., 2006).

Results

Influence on teachers' instructional enactments. The first research question intends to identify factors that relate to teachers' instructional practices (i.e., the number of laboratory investigations, teachers' enactment of AP science practice elements). The multi-level structural equation models indicate significant associations for teacher PD, teacher, and school characteristics across all disciplines and years (Table 12).

Table 12. Multi-level structural equation models.

	Biology Year 2		Biology Year 3		Chemistry Year 1		Chemistry Year 2		Physics Year 1	
	b	**(SE)**	***b***	**(SE)**	***b***	**(SE)**	***b***	**(SE)**	***b***	**(SE)**
Student-Level										
AP scores										
PSAT scores, b_1	0.647***	0.005	0.642***	0.005	0.648***	0.007	0.650***	0.007	0.629***	0.010
Mother's educational attainment (vs. no post-secondary), b_2										
Some post-secondary	0.010	0.012	0.022	0.013	-0.037*	0.016	-0.008	0.017	-0.006	0.017
Bachelor's	0.069***	0.013	0.070***	0.014	0.017	0.016	0.031~	0.016	0.040*	0.016
Graduate degree	0.084***	0.014	0.100***	0.015	0.031~	0.016	0.043*	0.018	0.053**	0.019
Teacher/School-Level										
AP scores (Intercept)										
Hours of AP instruction (in 10 h), b_3	0.012***	0.002	0.012***	0.002	0.017***	0.002	0.013***	0.003	0.011**	0.003
Enactment of laboratory investigations, b_4	0.008***	0.002	0.006**	0.002	0.025***	0.003	0.023***	0.003	0.011***	0.003
Enactment of AP practices, b_5	-0.004	0.010	-0.001	0.010	-0.029*	0.013	-0.008	0.014	-0.014	0.018
Administrative support, b_6	0.011	0.010	0.011	0.009	0.008	0.013	0.012	0.014	0.000	0.015
Percent free- or reduced lunch program, b_7	-0.369***	0.045	-0.309***	0.040	-0.734***	0.059	-0.675***	0.061	-0.482***	0.065
Enactment of laboratory investigations										
PD, b_8	0.345*	0.160	0.391*	0.161	0.542***	0.154	0.325*	0.164	0.854***	0.202
Years AP redesign experience, b_9	0.847*	0.415	0.391~	0.217	------	------	0.644	0.431	------	------
Years AP teaching experience, b_{10}	0.172***	0.025	0.138***	0.026	0.096***	0.020	0.064**	0.022	0.127***	0.029
Challenges with AP redesign, b_{11}	-0.500**	0.145	-0.664***	0.148	-0.768***	0.125	-0.799***	0.142	-0.593**	0.188
Administrative support, b_{12}	0.293*	0.144	-0.047	0.138	0.041	0.128	0.121	0.138	0.071	0.190
Percent free- or reduced lunch program, b_{13}	-1.341*	0.578	-1.468**	0.537	-2.588***	0.561	-3.155***	0.592	-1.258~	0.762
Enactment of AP practices										
PD, b_{14}	0.187***	0.028	0.192***	0.029	0.179***	0.030	0.216***	0.030	0.225***	0.033
Years AP redesign experience, b_{15}	-0.041	0.090	-0.051	0.043	------	------	0.122	0.084	------	------
Years AP teaching experience, b_{16}	0.007	0.005	0.013**	0.005	0.003	0.004	0.004	0.004	0.004	0.005
Challenges with AP redesign, b_{17}	-0.128***	0.027	-0.132***	0.030	-0.069*	0.027	-0.040	0.029	-0.116***	0.032
Administrative support, b_{18}	0.023	0.026	0.051~	0.027	0.007	0.025	0.005	0.026	0.060~	0.032
Percent free- or reduced lunch program, b_{19}	0.092	0.107	-0.023	0.103	0.014	0.108	0.329**	0.109	0.103	0.124
Comparative Fit Index (CFI)	0.990		0.986		0.984		0.984		0.989	
Tucker-Lewis Index (TLI)	0.985		0.980		0.977		0.977		0.984	
Root Mean Square Error of Approx. (RMSEA)	0.011		0.013		0.013		0.013		0.010	
Standard Root Mean Square Residual (SRMR)										
Student-level	0.000		0.000		0.000		0.000		0.000	
Teacher/school-level	0.042		0.053		0.040		0.045		0.043	

Note. ~ p < 0.10, * p < 0.05, ** p < 0.01, *** p < 0.001; latent variable has all letters capitalized.

Table 13. Description of the latent variable construct in the structural equation models.

	Biology Year 2		Biology Year 3		Chemistry Year 1		Chemistry Year 2		Physics Year 1	
	b	**(SE)**	***b***	**(SE)**	***b***	**(SE)**	***b***	**(SE)**	***b***	**(SE)**
PD										
Active learning	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000
Responsive agenda	1.081***	0.019	1.060***	0.021	1.064***	0.020	1.095***	0.019	1.042***	0.023
Modeling teaching	1.055***	0.028	1.042***	0.023	1.050***	0.026	1.075***	0.026	1.041***	0.027
Focus on student work	1.046***	0.027	1.026***	0.025	1.001***	0.026	1.048***	0.027	0.983***	0.028
Relationship building	1.083***	0.022	1.042***	0.020	1.056***	0.021	1.076***	0.019	1.033***	0.024
Effective support	1.139***	0.023	1.108***	0.021	1.116***	0.023	1.133***	0.024	1.091***	0.025
Number of conventional PDs	1.306***	0.026	1.279***	0.025	1.283***	0.028	1.355***	0.030	1.186***	0.036
Number of unconventional PDs	0.412***	0.039	0.458***	0.049	0.509***	0.041	0.650***	0.055	0.645***	0.077

Note. ~ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

PD participation. Teachers' PD participation is significantly positively associated with the number of enacted laboratory investigations (Biology Year 2: $b = 0.345$, $p < 0.05$; Biology Year 3: $b = 0.391$, $p < 0.05$; Chemistry Year 1: $b = 0.542$, $p < 0.001$; Chemistry Year 2: $b = 0.325$, $p < 0.05$; Physics Year 1: $b = 0.854$, $p < 0.001$) and teachers' enactment of AP science practices (Biology Year 2: $b = 0.187$, $p < 0.001$; Biology Year 3: $b = 0.192$, $p < 0.001$; Chemistry Year 1: $b = 0.179$, $p < 0.001$; Chemistry Year 2: $b = 0.216$, $p < 0.001$; Physics Year 1: $b = 0.225$, $p < 0.001$) across all disciplines and years. These findings indicates that PD participation has a direct influence of teachers' instructional practices.

Teacher characteristics. Regarding teacher characteristics, teachers' challenges with the AP redesign and teachers' AP teaching experience are significantly associated with instruction practices. A standard deviation increase in teachers' perceived challenges with the AP design is significantly related to teachers' enactment of 0.50-0.80 fewer laboratory investigations (Biology Year 2: $b = -0.500$, $p < 0.001$; Biology Year 3: $b = -0.664$, $p < 0.001$; Chemistry Year 1: $b = -0.768$, $p < 0.001$; Chemistry Year 2: $b = -0.799$, $p < 0.001$; Physics Year 1: $b = -0.593$, $p < 0.001$) and up to 0.13 standard deviations fewer AP science practices elements in their instruction (Biology Year 2: $b = -0.128$, $p < 0.001$; Biology Year 3: $b = -0.132$, $p < 0.001$; Chemistry Year 1: $b = -0.069$, $p < 0.05$; Chemistry Year 2: $b = 0.027$, n.s.; Physics Year 1: $b = -0.116$, $p < 0.001$). This indicates that teachers who feel more challenged by the AP redesign enact fewer AP redesign related instructional elements.

Notably, teachers' years of AP science teaching experience is only significantly associated with increases in the number of laboratory investigations but not with the enactment of AP science practice elements. A one-year increase in teachers' AP science teaching experience is significantly associated with teachers' enactment of 0.06-0.17 more laboratory investigations (Biology Year 2: $b = 0.172$, $p < 0.001$; Biology Year 3: $b = 0.138$, $p < 0.001$; Chemistry Year 1: $b = 0.096$, $p < 0.001$; Chemistry Year 2: $b = 0.064$, $p < 0.01$; Physics Year 1: $b = 0.127$, $p < 0.001$). This indicates that more experienced AP science teachers enact more laboratory investigations in their classrooms.

School context. The enrollment percentage of students in free- or reduced-priced lunch program is associated with the number of laboratory investigations across all years and disciplines. A ten percent increase of student enrollment in free- or reduced-priced lunch programs is significantly associated with 0.13-0.32 fewer enacted laboratory investigations in teachers' instruction (Biology Year 2: $b = -1.341$, $p < 0.05$; Biology Year 3: $b = -1.468$, $p < 0.01$; Chemistry Year 1: $b = -2.588$, $p < 0.001$; Chemistry Year 2: $b = -3.155$, $p < 0.001$; Physics Year 1: $b = -1.258$, $p < 0.10$). This indicates that teachers in schools that are economically challenged enact fewer instructional elements related to the AP redesign.

Influences on student performance. The second research question analyses how instructional enactments relate to students' performance on the AP science examinations. The multi-level structural equation models indicate significant associations for teaching elements, as well as student- and school-context characteristics across all disciplines and years (Table 12).

Classroom instruction. The hours of AP instruction and the number of enacted laboratory investigations have very weak, but significant, associations with students' AP scores across all disciplines and years. However, significance of these weak relationships could be viewed as an artifact of the large sample size. A ten-hour increase in AP science instruction is significantly associated with a 0.01-0.02 AP score increase (Biology Year 2: $b = 0.012$, $p < 0.001$; Biology Year 3: $b = 0.012$, $p < 0.001$; Chemistry Year 1: $b = 0.017$, $p < 0.001$; Chemistry Year 2: $b = 0.013$, $p < 0.001$; Physics Year 1: $b = 0.011$, $p < 0.01$). This indicates that students performed on average marginally better on the AP science examinations, the more AP science instruction exposure they receive. Enactment of one additional laboratory investigation is significantly associated with a 0.01-0.03 AP score increase (Biology Year 2: $b = 0.008$, $p < 0.001$; Biology Year 3: $b = 0.006$, $p < 0.01$; Chemistry Year 1: $b = 0.025$, $p < 0.001$; Chemistry Year 2: $b = 0.023$, $p < 0.001$; Physics Year 1: $b = 0.011$, $p < 0.001$). This indicates that enacting more laboratory investigation slightly increases student performance.

Student characteristics. Students' prior academic achievement and students' family background are significantly associated with students' AP science examination scores across all disciplines and years. A standard deviation increase in students' PSAT scores is significantly associated with a 0.63-0.65 AP score increase (Biology Year 2: $b = 0.647$, $p < 0.001$; Biology Year 3: $b = 0.642$, $p < 0.001$; Chemistry Year 1: $b = 0.648$, $p < 0.001$; Chemistry Year 2: $b = 0.650$, $p < 0.001$; Physics Year 1: $b = 0.629$, $p < 0.001$). This indicates that students' prior knowledge helps predict AP performance.

Higher maternal educational attainment is significantly associated with increased student performance. For instance, students whose mothers hold graduate degrees have up to 0.10 higher AP scores compared to students with mothers without postsecondary education (Biology Year 2: $b = 0.084$, $p < 0.001$; Biology Year 3: $b = 0.100$, $p < 0.001$; Chemistry Year 1: $b = 0.031$, $p < 0.10$; Chemistry Year 2: $b = 0.043$, $p < 0.05$; Physics Year 1: $b = 0.053$, $p < 0.01$). Similarly, students whose mothers hold bachelor's degrees have up to 0.07 higher AP scores compared to students with mothers without postsecondary education (Biology Year 2: $b = 0.069$, $p < 0.001$; Biology Year 3: $b = 0.070$, $p < 0.001$; Chemistry Year 1: $b = 0.017$, n.s.; Chemistry Year 2: $b = 0.031$, $p < 0.10$; Physics Year 1: $b = 0.040$, $p < 0.05$). This indicates that students with better educated parents are performing slightly better on the AP examinations.

School context. The school-level enrollment percentage in free- or reduced-priced lunch program is significantly associated with students' AP scores across all disciplines and years. A ten percent increase in students enrolled in free- or reduced-priced lunch programs is significantly associated with a 0.03-0.07 AP score decrease (Biology Year 2: $b = -0.369$, $p < 0.001$; Biology Year 3: $b = -0.309$, $p < 0.01$; Chemistry Year 1: $b = -0.734$, $p < 0.001$; Chemistry Year 2: $b = -0.675$, $p < 0.001$; Physics Year 1: $b = -0.482$, $p < 0.001$). This indicates that school-level socioeconomic factors can help predict students' AP performance.

Discussion

Scholarly significance. This large-scale, quantitative study contributes to the in-service secondary science teacher education research base by analyzing and validating relationships described in Desimone's (2009) framework for studying the effects of PD. The context of the AP science redesign as a nationwide, top-down curriculum reform connected to changes in high-stakes national examinations provides a unique context for such educational research in the United States. This is the first project that has access to such a comprehensive national data base with student-, teacher-, and school-level variables across multiple science discipline to examine a curriculum and examination reform in the high school science context. Therefore, this study might also allow for generalizations to future or current nationwide curriculum reforms such as the Common Core State Standards Initiative (2010a, 2010b) or the Next Generation Science Standards (NGSS; NGSS Lead States, 2013) for how teachers respond to such large-scale changes in the educational landscape. With respect to the applied methodology, it is one of few studies that analyzes relationships between school context, PD participation, teacher and teaching characteristics, and student learning using multi-level structural equation modeling.

Conclusions, implications, and future work. The findings of this study provide support for some of the relationships described in Desimone's (2009) framework across multiple science disciplines and across different years of the science reform implementation. The main two contributions and its implications are as follows:

First and foremost, this study validates some relationships described in Desimone's (2009) framework for studying the effects of PD. Teachers' PD participation is positively associated with teachers' classroom practice. However, the observed measures portraying elements of instructional practice only have a very small influence on students' performance in the expected direction. This implies that PD participation can make a difference for teachers to change their classroom teaching. This supports perspectives that PD can help teachers to align their instruction with curriculum reforms (e.g., Correnti, 2007; Garet et al., 2001; Penuel et al., 2007). The weak link of instructional elements to student achievement, which corresponds with previous research that found positive but very small effects of reform-oriented instructional elements on student achievement (e.g., Hamilton et al., 2003), could also in part serve as an alternative explanation why several recent PD effectiveness studies did not find considerable direct effects of teachers' PD participation on student achievement (e.g., Arens et al., 2012; Bos et al., 2012; Garet et al., 2008, 2011; Jacob & McGovern, 2015). While PD participation might have produced growth in teachers' knowledge and skills that fostered changes in classroom teaching, such instructional changes might not have concurred with effective teaching practices, thus, lacking increases of student learning. Thus, this study cautions to not assume inevitable presences of each relationship in Desimone's (2009) framework without testing such assumptions in the corresponding context.

Second, teachers' instruction and student learning are situated within and influenced by both students' and teachers' individual contexts. On the teacher-level, contextual features such as SES and teachers' years of teaching experience substantially influence teachers' classroom instruction. This mirrors previous research that emphasizes the importance of teacher knowledge, teaching experience, and other teacher-level influences, as well as local contexts characteristics such as school affluence for shaping classroom instruction (e.g., Garet et al., 2008; Ingvarson, Meiers, & Beavis, 2005; Kennedy, 2010; Supovitz & Turner, 2000). Similarly, contextual features on the student-level such as students' prior achievement and parental educational attainment substantially influence student learning. These findings are in accordance with previous research that detected relationships of prior knowledge measures (i.e., PSAT scores) with students' current knowledge (i.e., AP scores) (e.g., Ewing et al., 2006; Zhang et al., 2014), as well as research that relates students' family background with student achievement (Davis-Kean, 2005; Desforges & Abouchaar, 2003; Woessmann, 2004). Thus, this study implies that the mission of advancing teachers' instruction and fostering student learning is multi-faceted and should be approached from several perspectives.

Overall, this study reinforces calls to provide teachers with high-quality professional learning opportunities, to retain experienced teachers in schools, and to guide teachers toward classroom practices that enhance student learning. Furthermore, this study also motivates and illustrates the importance for advancing research in at least two directions. The first set of future studies relates to Opfer and Pedders' (2011) conceptualization that teacher professional learning is embedded in the complex system of schooling with its numerous dynamic, interdependent relationships. Motivated by the multitude of detected relationships on teachers' instruction and student learning and, future research could go beyond what Opfer and Pedder (2011) describe as “process-product logic” (p. 384) and apply a complexity theory lens (Byrne & Callaghan, 2014; Cochran-Smith et al., 2014; Opfer & Pedder, 2011). The second set of studies is motivated by the detected weak relationship of instructional practices with students’ AP scores, which suggests to further analyze immediate influences of specific teaching practices on student learning in more depth. In particular, further research should attempt to identify sets of instructional practices that relate to increased student learning, which in turn should inform future teacher PD activities.

Chapter Four – New forms of professional development: Analyzing high school science teachers' engagement in microblogging platforms for professional learning

Abstract

This mixed-methods observational study analyzes Advanced Placement (AP) Biology teachers' engagement in microblogging for their professional development (PD). Data from three hashtag-based Twitter communities, #apbiochat, #apbioleaderacad, and #apbioleaderacademy (121 users; 2,253 tweets), are analyzed using methodological approaches including educational data mining, qualitative two-cycle content analysis, social network analysis, linear and logistic regression analyses, and hierarchical linear modeling. Results indicate that Twitter adheres to standards of high-quality PD and has the potential to complement more traditional PD activities. Notably, Twitter's non-hierarchical leadership affords shared content creation and distribution. Additionally, Twitter allows for different temporal participation patterns supporting the personalization of learning aligned to teachers' needs and preferences. Furthermore, teachers frame their interactions on Twitter positively, thus, creating supportive learning environments that might reduce teachers' perceived isolation.

Keywords: Microblogging, science education, professional development, virtual communities of practice, Advanced Placement

In times of accelerated technological advancements traditional framings of images of teacher professional development (PD) might change in the coming decade. Teachers are offered opportunities to engage in online courses and to participate in online learning communities that might extend professional learning activities in traditional face-to-face settings. One example of such an environment is Twitter. Twitter is a microblogging platform that allows users to communicate with their followers through short messages. Besides text information, tweets can also include images, videos, and links to other websites. As of June 30, 2016, Twitter attracted 313 million monthly active users who accumulated one billion unique visits per month to websites with embedded tweets (Twitter, Inc., 2017). Features that distinguish Twitter from other online communities are its usability (e.g., limited technology prior knowledge necessary), accessibility (e.g., support of mobile applications), personalization (e.g., unique information displayed to every user with individual feeds), low financial costs (e.g., no sign-up fees or subscription-based participation model), breadth and depth of available information (e.g., diverse user groups with world-wide scope), limited time commitments for individual tweets (e.g., 140-character limit), and dynamic display of new information (e.g., real-time updates) (Carpenter, 2015; Carpenter & Krutka, 2014, 2015; Ebner & Schiefner, 2008; Java, Song, Finin, & Tseng, 2007; Zhao & Rosson, 2009). Twitter's increased popularity with teachers evokes questions such as: how does engagement on Twitter complement more traditional forms of professional learning? Does Twitter exhibit characteristics that might be defined as high-quality PD?

This study explores teachers' use of Twitter in the context of the redesign of the Advanced Placement (AP) examinations in the sciences. AP courses provide rigorous, college-level learning experiences for high-school students. AP course and examination taking is positively associated with academic success in students' higher education careers as indicated through higher enrollment rates in four-year postsecondary institutions (Chajewski et al., 2011), increased college graduation rates (Dougherty et al., 2006; Hargrove et al., 2008; Mattern et al., 2013), and higher college-level grade point averages (Hargrove et al., 2008; Patterson et al., 2011; T. P. Scott et al., 2010). In response to recommendations from the National Research Council (2002), College Board, the provider of the AP examinations, redesigned the AP sciences examinations and curricula. The first redesigned AP Biology examination is administered in May 2013. The AP science redesign decreased the former emphasis on memorization and algorithmic procedures while foregrounding deeper content understanding, underlying disciplinary concepts, scientific inquiry, science practices, critical thinking, and reasoning (e.g., Magrogan, 2014; Yaron, 2014). Many changes in the AP science examinations and curricula are consistent with the Next Generation Science Standards (NGSS; NGSS Lead States, 2013). Given the large-scale curriculum changes and the high-stakes nature of the AP examinations, teachers are highly incentivized to engage in PD activities to improve their instruction.

Decades of systematic empirical research studies on the impacts of teacher PD identified several design elements contributing to high-quality PD such as practice orientation, focus on content knowledge, coherence with school and teaching contexts, collaboration and community building among colleagues, and intensity and continuation of professional learning (Darling-Hammond & Richardson, 2009; Darling-Hammond et al., 2009; Desimone, 2009; Desimone & Garet, 2015; Kennedy, 2016). Given the potential of new technologies to be used for teacher PD, calls for empirical research that analyzes the potential of online teacher learning (Borko et al., 2010; Dede, 2006; Dede, Ketelhut, Whitehouse, Breit, & McCloskey, 2008; Macià & García, 2016) are not surprising. Previous research on teachers' use of online communities as PD indicates connections with emotional support (Carpenter & Krutka, 2014; Davis, 2015; Deryakulu & Olkun, 2007), access to resources that can facilitate knowledge gains (Carpenter & Krutka, 2014; Kelly & Antonio, 2016; Macià & García, 2016; Riding, 2001; Trust, 2016), potential to reflect on and improve instruction (Deryakulu & Olkun, 2007; Fishman et al., 2014; Macià & García, 2016; Visser, Evering, & Barrett, 2014; Zuidema, 2012), and increased student achievement (Fishman et al., 2014).

Educators are recognizing the potential of Twitter as a useful tool for enhancing their professional life. For instance, practitioner-focused publications describe how Twitter can transform educational practices such as interacting with students, parents, and administrators (e.g., Kurtz, 2009; Porterfield & Carnes, 2011), change instructional practices (e.g., Domizi, 2013; Krutka & Milton, 2013), or – on an anecdotal level – contribute to professional learning (e.g., Boss, 2008; Trinkle, 2009). However, the scholarly literature base analyzing teachers' use of Twitter as a form of PD for K-12 teachers is limited. As of now, most research on Twitter as PD is focused on descriptions of teachers' Twitter usage patterns (e.g., Carpenter & Krutka, 2014, 2015; Forte, Humphreys, & Park, 2012; Risser, 2013; N. Wright, 2010), while only a few studies provide insights on perceived effects of pre-service and in-service teachers' engagement on Twitter. Such studies summarize that benefits of Twitter include the availability of resources, encouragement to reflect on instructional practice, and building of relationships with colleagues to reduce perceived professional isolation (Carpenter, 2015; Carpenter & Krutka, 2014; Lord & Lomicka, 2014; Mills, 2014; Wesely, 2013; N. Wright, 2010). However, empirical studies that analyze how teachers' participation on Twitter might complement more traditional PD or how microblogging fulfills characteristics of high-quality PD are currently underrepresented in the scholarly literature base.

Theoretical framework

This observational mixed-methods study is guided by Bruns and Moes' (2013) framework that describes user interactions on Twitter with three cross-layered categories (i.e., micro-level: reply conversations, meso-level: follower-followee networks, macro-level: hashtagged exchanges) and Desimone's (2009) summary of decades of PD effectiveness research that identifies high-quality PD characteristics. In particular, this study focuses on Bruns and Moes' (2013) macro-level conversational practices and analyzes interactions in hashtag-based communities. Additionally, this study explores whether teachers' Twitter usage fulfills the 'collective participation' and 'duration' PD design characteristics that Desimone (2009) highlights as important for high-quality PD experiences.

Framing user interactions on Twitter. Twitter's design infrastructure affords a multitude of activities that can enhance users' knowledge. For instance, informal professional communities can allow the generation of social capital (Forte et al., 2012; Zhao & Rosson, 2009). Activities on Twitter include following high-profile users, purposeful information seeking, exposure to and sharing of knowledge and resources, building and fostering friendships, and providing and receiving emotional support, among other activities (Carpenter & Krutka, 2014, 2015; Ebner, Lienhardt, Rohs, & Meyer, 2010; Ebner & Schiefner, 2008; Forte et al., 2012; Risser, 2013; Zhao & Rosson, 2009).

More broadly, Bruns and Moe (2013) describe users' conversational practices on Twitter on interrelated micro-, meso-, and macro-level. Micro-level conversational practices include replying and/or mentioning other users in tweets (@-sign preceding the username) that afford informal collaborations between users (Bruns & Moe, 2013; Honeycutt & Herring, 2009). On the meso-level, communication is fostered through asymmetric follower-followee network structures

(Bruns & Moe, 2013). Such structures are called directed networks. Users can subscribe to receive the public tweets from other users in real-time ('following') without a required reciprocal following. Tweets are disseminated to users' entire follower networks, often hundreds of other users. On the macro-level, users disseminate tweets to a broader audience by joining hashtag-based conversations (#-sign preceding the name of conversation) that are not restricted to users' follower-networks (Bruns & Moe, 2013). Hashtags have conversational and social tagging functions that allow users to filter and promote content, foster conversations, and initiate and sustain collaborations with other users (Bruns & Moe, 2013; Huang, Thornton, & Efthimiadis, 2010).

Collective and collaborative professional learning. Desimone (2009) defines the high-quality PD characteristics 'collective participation' as "[PD] participation of teachers from the same school, grade, or department. Such arrangements set up potential interaction and discourse, which can be a powerful form of teacher learning" (p. 184). Notably, this definition has a geographic-related and an activity-related component. AP Biology teachers are often the only AP Biology teachers in their school. Local contexts often constrain teachers to collaboratively engage in PD targeted towards the redesigned AP Biology curriculum with other teachers from their school. Therefore, meaningful collaborative interactions and discourses with other AP Biology teachers in virtual learning communities can overcome geographical boundaries. Examples of such collaborative activities on Twitter include providing socio-emotional encouragement and support, discussing strategies about aligning instructional practices with the AP curriculum reform, and populating shared web-based storage folders of file hosting services with instructional materials.

Twitter as a collaborative learning environment. Collective PD participation and collaboration among educators can enhance teacher learning and to change instructional practices (Garet et al., 2001; Penuel et al., 2007). Communities of practice are a prime example of such collaborative environments that facilitate learning situated in individuals' contexts (Lave, 1991; Wenger, 1998; Wenger, Trayner, & De Laat, 2011) and some researchers argue that participation on Twitter can enable learners to form virtual communities of practice (Lord & Lomicka, 2014; Wesely, 2013). Whether Twitter provides more informal, democratic, and bottom-up collaboration and learning compared to more traditional PD activities with more formal, hierarchical, and top-down information distribution structures is a focal question of this study.

Several of Twitter's design characteristics support a perspective that Twitter affords more informal, democratic, and bottom-up collaborative learning. *First*, Twitter's peer-to-peer interaction structure affords a reduced disconnect between learners and experts. The flattening of hierarchical communication structures might afford increases of informal collaborations and shared responsibilities for learning processes (Ardichvili, 2008; Kirschner & Lai, 2007). For instance, Carpenter (2015) describes how a pre-service teacher, who rarely participates in face-to-face discussions, exhibits prolific engagement in collaborative activities on Twitter. *Second*, Twitter's asynchronous following-followee structure and personalized display of tweets affords learners to personalize their experiences. In contrast to "one-size-fits-all" approach of some traditional PD activities, teachers on Twitter can interact with selected resources and participants based on their individual needs and contexts (Carpenter & Krutka, 2014, 2015; Zhao & Rosson, 2009). For instance, some teachers might only collaborate with educators on Twitter about specific elements of the AP curriculum framework. Others might choose to engage in lurking behavior such as reading tweets, downloading resources, and following other users. Although, lurkers do not contribute own content, they can be viewed as community members of the with own motivations and participation benefits (e.g., Edelmann, 2013; Fischer, Frumin, et al., 2016; Preece, Nonnecke, & Andrews, 2004). *Third*, Twitter removes potential participation barriers which affords collaborations of more diverse teacher populations. Twitter imposes no financial costs to teachers as only an internet connection is required to access large quantities of resources (materials, people, and communities). This reduces socioeconomic status (SES) induced participation barriers. Also, Twitter learning communities can be accessed anywhere, anytime, and with any desired intensity (Carpenter & Krutka, 2014; Ebner et al., 2010; Ebner & Schiefner, 2008; Zhao & Rosson, 2009), which reduces potential geographic and temporal participation constraints. For instance, teachers in low-SES schools who cannot participate in traditional PD activities due to insufficient funding or AP teachers located outside U.S. territory could view Twitter as an alternative to engage in collaborative, AP-related professional learning. This assumes, of course, that Twitter has value as a vehicle for professional learning, which is the question at the heart of this study.

Twitter as a supportive learning environment. In the teaching profession, teachers frequently experience isolation, which does not only influence teachers' well-being but also their teaching performance. For instance, Moore and Chae (2007) indicate that beginning teachers are more likely to suffer from emotional stress and isolation if school environment does not meet teachers' support needs. Supportive environments are important as emotions have profound influences on motivation, cognitive processes and strategies, decision making processes, and learning outcomes (e.g., Efklides & Volet, 2005; Kim & Pekrun, 2014; Pekrun, Elliot, & Maier, 2009; Pekrun, Goetz, Titz, & Perry, 2002; Sansone & Thoman, 2005). In particular, teachers' professional learning can be deterred by perceived feelings of isolation. However, effects are bidirectional as learning processes accompanied with positive emotions (e.g., perceived self-efficacy, value of tasks) relate to greater learning outcomes, whereas negative emotions negatively relate to learning outcomes (Gläser-Zikuda, Fuß, Laukenmann, Metz, & Randler, 2005; Pekrun, Goetz, Daniels, Stupnisky, & Perry, 2010; Zusho, Pintrich, & Coppola, 2003).

Research indicates that online communities have potential to provide positive and supportive environments for professional learning that promote collaboration and reduce isolation (Dodor, Sira, & Hausafus, 2010; Hough, Smithey, & Evertson, 2004; Lieberman & Mace, 2010). In particular, Twitter is often described as supportive, encouraging, and positive environment (Carpenter & Krutka, 2014, 2015; Wesely, 2013; N. Wright, 2010). For instance, Wesely (2013) describes how teachers who are isolated in individual school contexts utilize Twitter communities to create meaningful and supportive relationships with colleagues. However, Twitter use can also have adversary effects. For instance, the public nature of tweets, in accordance with the immediacy of a mostly anonymous participation culture, can evoke responses that include extreme forms of disapproval and harsh commentary (Burbules, 2016; Mandavilli, 2011). Also, student-teacher relationships can be impacted if students view their teachers' social media interactions as inappropriate or unprofessional (DeGroot, Young, & VanSlette, 2015; Mazer, Murphy, & Simonds, 2007).

Temporal aspects of PD participation. Twitter provides a platform for professional learning with respect to teachers' preferred temporal engagement pattern that offers teachers flexibility with respect to immediate feedback and personalized just-in-time information (Carpenter & Krutka, 2014; Ebner et al., 2010; Ebner & Schiefner, 2008; Zhao & Rosson, 2009). Teachers' intensity and frequency of participation has no upper bound as permanently publicly available information on Twitter allows for asynchronous learning. Both intensity and continuation of PD participation are integral factors for teacher learning (e.g., Darling-Hammond et al., 2009; Desimone, 2009; Kennedy, 2016). 'Intensity' refers to the contact hours and 'continuation' to both time span and frequency of engagement in professional learning. While duration thresholds are not specified, Desimone's (2009) estimate of 20 hours contact time and Darling-Hammond and colleagues' (2009) estimate of 50 hours spread across 6-12 months provide some insights on lower PD duration bounds to yield teacher knowledge and student performance gains. For example, the study of Garet et al. (2001) indicate that the number of contact hours engaging in PD is significantly associated with changes in teachers' instructional practices and other features of high-quality PD such as active learning, coherence, and focus on content knowledge. Similarly, Supovitz and Turners' (2000) find that high PD durations (≥80 hours) are significantly associated with more enactment of inquiry-based instructional practices, whereas low PD durations (≤19 hours) are significantly associated with less inquiry-based instruction.

Research questions

This study explores how teachers' interaction and engagement in professional learning on Twitter might complement more traditional forms of professional development, as well as whether Twitter exhibits PD features Desimone (2009) relates to high-quality PD. 'Collective participation' is explored by analyzing hierarchical participation structures (research question 1) and affective support structures (research question 2). "Duration" is examined by analyzing temporal participation patterns (research question 3). The research questions are as follows:

Research Question 1: Are participation structures in AP teacher Twitter communities organized similarly to more traditional, hierarchically organized professional learning activities?

a. Are AP Biology teachers who share content knowledge or resources on Twitter more or less likely to be influential in the corresponding Twitter communities?
b. Are AP Biology teachers who seek information or share resources on Twitter more or less likely to be central in the corresponding Twitter communities?
c. Are AP Biology teachers who organize teacher chats on Twitter more or less likely to have a higher ability to connect with other teachers in the corresponding Twitter communities?

Research Question 2: Do AP teacher Twitter communities provide a positive, supportive environment for teachers engaging in professional learning activities?

a. Do topics AP Biology teachers discuss in the Twitter communities exhibit mostly positive, negative, or neither positive nor negative sentiments?
b. Do AP Biology teachers engage (i.e., like and retweet) more with positive, negative, or neither positive nor negative tweets in the Twitter communities?

Research Question 3: Do teachers' temporal Twitter usage patterns in AP teacher Twitter communities complement more traditional forms of professional learning activities?

a. What are AP Biology teachers' participation patterns in the Twitter communities regarding frequency and lifespan of participation?

b. What tweet content, tweet sentiment, tweet characteristics, and community participation characteristics are associated with AP Biology teachers' lifespan of participation in the Twitter communities?

Methods

Data sources and sample. This observational study analyzes voluntarily contributed public data from three purposefully selected hashtag-based AP Biology Twitter teacher communities (*#apbiochat*, *#apbioleaderacademy*, *#apbioleaderacad*). This study adheres to high ethical standards to protect users' privacy, despite all data being publicly available, by following ethical guidelines for social media research (Bruckman, 2006; Moreno, Goniu, Moreno, & Diekema, 2013). For instance, instead of verbatim quotations of tweets in this manuscript that might lead to an identification of teachers' true identities, synthetic tweets with identical content and sentiment are generated to illustrate relevant concepts. This is similar to practices of generating synthetic data sets that protect user's privacy in large-scale quantitative analyses (e.g., Abowd & Lane, 2004; Reiter, 2002). These synthetic tweets are only used for illustrative purposes and not for any analyses.

AP teacher communities are selected because the top-down, national AP science curriculum reform incentives teachers to engage in PD to align their classroom instruction to the new curriculum. The first redesigned AP Biology exam was administered in 2013 compared to AP Chemistry and AP Physics in 2014 and 2015, respectively. Thus, Biology communities are selected because they afford the longest observational period for science teacher learning on Twitter. Hashtag-based communities are chosen to analyze macro-level user interactions (Bruns & Moe, 2013). The *#apbiochat* community is selected because teachers report frequent engagement in this Twitter community in response to web-based surveys connected to a large-scale longitudinal research project examining this AP science curriculum reform (e.g., Fischer, Fishman, et al., 2016; Fishman et al., 2014),. The *#apbioleaderacademy* and *#apbioleaderacad* communities are selected because of their affiliation with the NABT/BSCS AP Biology Leadership Academy, an intense two-year long PD program that includes week-long face-to-face workshops, conference participations, and online support throughout the program.

The full public tweet history from the first tweet with the corresponding hashtags until June 14, 2016 (four weeks after the 2016 AP Biology examination) is retrieved and cleaned using Twitter's search function, the Twitter API, the R package twitteR, and custom Python scripts. Additionally, Python scripts are used to collect biographical information and descriptive Twitter usage data. In total, the three online communities contain 2,276 tweets from 135 users. Users not identifiable as teachers, school administrators, or representatives from professional organizations are removed from the data set reducing the data set to 121 users (93 teachers) posting 2,253 tweets (2,040 tweets authored by teachers). The research questions are answered exclusively with teacher data. Only variables that describe different facets of teachers' relational positions in the communities also utilize data from school administrators and representatives from professional organizations.

Measures. ***Qualitative tweet measures.*** On the tweet-level, qualitative coding approaches are applied to describe tweet content and tweet sentiment. The unit of analysis is a single tweet. The initial coding schema uses an exploratory two-cycle coding strategy applying descriptive coding (first cycle) and subcoding (second cycle) (Miles et al., 2014). After multiple iterative improvements of the inductively developed coding guidelines, a final list of codes was chosen and treated as the deductive coding framework. Tweets are recoded based on this final list of codes. Following Lombard, Snyder-Duch, and Bracken (2002), the reliability of the coding scheme is evaluated through three additional external coders who independently coded an identical subset of 225 randomly selected tweets (more than 10% of the full sample) after a face-to-face training session. Interrater reliability of the coding schema was established by achieving 88.8 mean percentage agreement and an average Cohen's κ rating of 0.73 across all coding scales. This meets benchmarks of "substantial" agreement (Landis & Koch, 1977, p. 165).

Tweet content is coded based on seven categories related to AP learning and teaching, (a) sharing AP Biology content knowledge, (b) sharing resources, (c) seeking information, (d) organizing PD on Twitter, (e) mentioning curricular elements, (f) sharing information about laboratory investigations, and (g) assessments. Each tweet is either classified as exhibiting the characteristics of a category (coded as "1") or not (coded as "0"). Tweets can exhibit characteristics of any number of categories. Table 14 provides descriptive information on the tweet content categories on both tweet- and teacher-level (summative scores). Notably, teachers' tweets most frequently shared resources (14.6%), sought information (12.3%), and related to assessments (9.2%).

Table 14. Descriptive information of tweet content measures.

	Cohen's κ	Percentage agreement	N (%) [tweet-level]	M (SD) [teacher-level]
AP Biology content	0.81	96.4%	131 (6.42)	1.41 (3.52)
Share resources	0.78	88.9%	297 (14.56)	3.19 (9.41)
Seek information	0.71	90.2%	250 (12.25)	2.69 (7.53)
Organize PD	0.76	92.4%	168 (8.24)	1.81 (6.14)
Curriculum elements	0.70	94.2%	125 (6.13)	1.34 (3.35)
Labs	0.76	91.6%	175 (8.58)	1.88 (5.00)
Assessments	0.65	87.1%	187 (9.17)	2.01 (5.85)

Note. N_{tweet} = 2,040, $N_{teacher}$ = 93.

Tweets classified as *sharing AP Biology content knowledge* provide content information relevant for AP Biology (including statistics knowledge necessary to analyze laboratory investigations), “common content knowledge” (Ball et al., 2008), common misconceptions, use of biological language (e.g., “banned/dead word lists”), and recommendations for retrieving additional resources for content knowledge learning. Tweets classified as *sharing resources* provide either information on accessing additional resources (e.g., AP Biology related websites, instructional materials, and PD activities) or give recommendations to use these resources. Tweets classified as *seeking information* ask questions related to AP learning and teaching or request resources related to student and teacher learning, instructional enactments, curricular standards, or assessments. Tweets classified as *organizing PD on Twitter* include discussions on Twitter chat topics, scheduling Twitter chats, sending reminders regarding upcoming Twitter chats, recruiting participants, and confirming absence or participation in upcoming Twitter chats. In particular, tweets are not classified as organizing PD on Twitter if teachers use Twitter as a platform to organize meetings at conferences or other face-to-face events. Tweets classified as *curricular elements* include references to other state or national curricula, the AP lab manual, practice exams, conceptual flow graphics, standards-based grading, free- and open-response questions, as well as mentioning AP curriculum framework elements (e.g., ‘Big Ideas,’ ‘Science Practices,’ ‘Enduring Understandings,’ ‘Learning Objectives’). Tweets classified as *laboratory investigations* include descriptions of experiments, laboratory equipment and supplies, and lab reports. Tweets classified as *assessments* include information about the AP Biology examinations, test preparations, and summative and formative assessments strategies in AP courses. Table 15 illustrates these categories with exemplary tweets for each content category.

Table 15. Synthetic exemplary tweets for each tweet content category.

AP Biology content	Human DNA is stored in 23 chromosomes pairs contained within cell nuclei. And it's pretty: http://website.com/dna-pics #scichat #apbiochat
Share resources	#apbioleaderacad I uploaded my lessons plans to @USER's #dropbox folder: http://dropbox.com/sf/fhj184us3 - feel free to use and modify them!
Seek information	@USER so how do you help your students reflect on the labs? more guidance? less guidance? #apbiochat
Organize PD	Our #apbiochat starts today at 8 pm EST -- join us and talk about how you prepare students for the FRQs [A/N: Free- and open-response questions]
Curriculum elements	@USER College Board's LO [A/N: Learning Objectives] are crucial to my teaching. In the end, that's what is assessed on the AP exam. #apbioleaderacad
Labs	@USER I often use #Vernier labs for teaching inquiry. Their support is also very helpful. #apbiochat
Assessments	I wish I could share some of the new MC [A/N: Multiple-choice questions] and FRQs with my students to better prepare them for the #apbio exam #apbiochat

Tweet sentiment coding follows an emotion coding approach (Miles et al., 2014) and classifies tweets as *more positive*, *more negative*, and *not exclusively positive or negative*. The unit of analysis is a single tweet. Each tweet is assigned one sentiment category and one only. Tweet sentiment evaluations also account for tone, emoticons, hashtags, sarcasm, and irony. Tweet sentiments classified as *more positive* include expressions of joy, excitement, liking, motivation, inspiration, and thankfulness, among others. Tweet sentiments classified as *more negative* include expressions of being overwhelmed, struggle, anxiety, and admittance of mistakes, among others. Tweet sentiments classified as *not exclusively positive or negative* include tweets that exhibit neutral, neither positive nor negative sentiment, or both positive and negative sentiments. Table 16 provides descriptive information on the tweet sentiment categories on both tweet-level and teacher-level (summative scores) and Table 17 illustrates these categories with synthetic exemplary tweets.

Table 16. Descriptive information of tweet sentiment measures.

	N (%) [tweet-level]	M (SD) [teacher-level]
Positive sentiment	585 (28.68)	6.29 (15.28)
Negative sentiment	133 (6.52)	1.43 (4.16)
Not exclusively positive or negative sentiment	1,322 (64.80)	14.22 (42.61)

Note. Cohen's κ = 0.65; Percentage agreement: 69.3%; N_{tweet} = 2,040, $N_{teacher}$ = 93.

Table 17. Synthetic exemplary tweets for each tweet sentiment category.

Positive sentiment	#apbiochat has been such a tremendously helpful resource for my teaching! So glad that @USER convinced me to join. Thank you!
Negative sentiment	@USER I spent lots of time and $$$ and got almost nothing out of it. Expected more from @CONFERENCE_PROVIDER #apbiochat
Not exclusively positive or negative sentiment	#apbiochat starts in 2 hours. We will discuss how to do #inquiry in the classroom.

Quantitative tweet measures. Quantitative tweet information include the number of retweets and likes a tweet received, the number of mentions, hashtags, and links incorporated in a tweet, teachers' lifespan of community participation (number of days between first and last tweet), and frequency of teachers' engagement in the communities (total number of tweets divided by lifespan). Table 18 provides descriptive information for quantitative tweet categories on both tweet-level and teacher-level (summative scores).

Table 18. Descriptive information, quantitative tweet measures.

	M (SD) [tweet-level]	M (SD) [teacher-level]
Tweet characteristics		
Retweets	0.21 (0.84)	4.56 (11.74)
Likes	0.83 (1.60)	18.27 (48.89)
Mentions	1.18 (1.25)	25.96 (88.97)
Hashtags	1.33 (0.71)	29.18 (74.22)
Links	0.10 (0.31)	2.30 (6.64)
Community participation		
Lifespan (days)	-	143.81 (231.48)
Tweets/day	-	1.11 (1.95)

Note. $N_{tweet} = 2,040$, $N_{teacher} = 93$.

Inferential social network measures. Bruns and Moes' (2013) micro-level conversational practice of "mentioning" is examined by evaluating the relational positions of teachers in the selected Twitter communities. The "mentions network" is comprised of all interactions of user A mentioning (i.e. including the "@"-sign in their tweet) user B in the selected communities. The mentions network uses data from teachers, school administrators, and representatives of professional organizations. Data from school administrators and representatives of professional organizations is included in the computations of social network characteristics because teachers frequently interact with non-teachers. Omittance of this data might misrepresent teachers' relational positions. Nonetheless, all research questions are explored only using teacher data.

Social network diagrams (Figure 5-Figure 9) of the mentions network are visualized by the ForceAtlas2 algorithm (Jacomy, Venturini, Heymann, & Bastian, 2014) with the open-source software Gephi (Bastian, Heymann, & Jacomy, 2009). Visualizations can be interpreted as follows: Nodes, the circles, represent users (i.e., teachers, school administrators, or representatives of professional organizations) in the mentions network. Edges, the connecting line between two circles, represent the connection of user A (source node) mentioning user B (target node). Tweets not mentioning other users are treated as self-referential (source identical to target). Edge thickness represents the number of mentions between two users. Edge colors are identical to the color of the source node. Clockwise-curved edges illustrate that the source node mentions the target node, and vice versa. To better illustrate the directed network structure, visualizations are centered on the largest connected network (Figure 5-Figure 9). Some distant nodes are not represented in the illustrations to increase the readability of the visualizations (Figure 6-Figure 9). Node sizes reflect users' in-degree (number of users mentioning the user). The visualizations illustrate relationships between users and provide insights on the relative importance of users based on their positioning in the network. For instance, teachers mostly mention other teachers and rarely mention representatives from professional organizations in their tweets. Also, representatives from professional organizations hold less prominent roles in the communities, which provides support to focus the subsequent analysis on teachers.

Social network analysis (SNA) measures are computed to analyze the hierarchical structures of teachers within the communities. The literature base that uses SNA methods to analyze social ties among educators has grown in recent years (e.g., Atteberry & Bryk, 2010; Coburn et al., 2012; Penuel & Riel, 2007). For instance, Atteberry and Bryks' (2010) study of the implementations of a coaching-based literacy initiative in 17 schools uses SNA measures to describe school contexts with respect to the interconnectivity among members of the school community, the isolation of teachers, and the centrality of the coach.

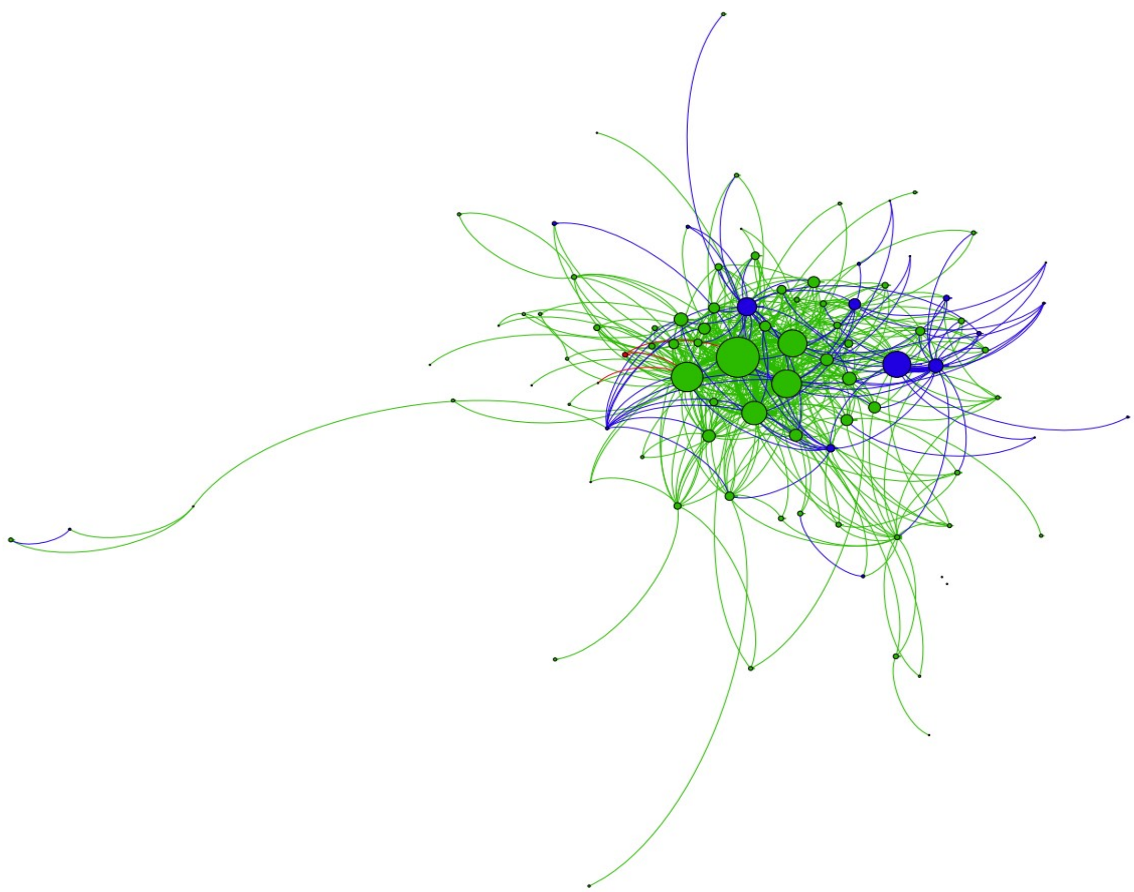

Figure 5. Visualization of the mentions network by user groups: teachers (green), school administrators (red), representatives from professional organizations (blue).

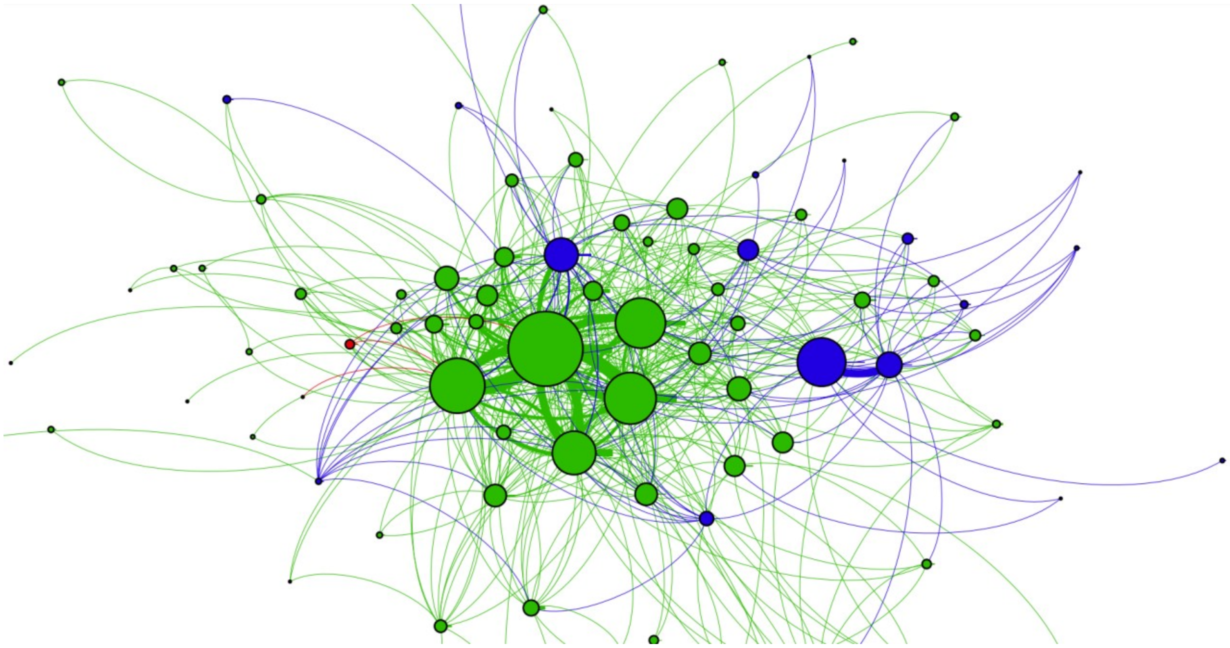

Figure 6. Visualization of the mentions network by user groups, zoomed-in: teachers (green), school administrators (red), representatives from professional organizations (blue).

This study uses SNA methods to better understand collaboration patterns and information flows among teachers. In particular, hierarchical structures within these teacher collaborations are described and explored through the computation of eigenvector centrality, closeness centrality, and betweenness centrality measures (e.g., Daly, 2010; Knoke & Yang, 2008; J. Scott, 2013). *Eigenvector centrality* is computed to describe teachers' influence in the selected communities (Figure 7, Table 19). This measure does not only account for users' own connectedness but also describes their neighbors' connectedness within the network. For instance, teachers with high eigenvector centrality could be interpreted to have more 'prestige', and thus, fulfill a more pronounced role in the communities. Other teachers might more likely follow guidance from such 'high-prestige' teachers. *Closeness centrality* is computed to classify teachers' centrality in the selected communities (Figure 8, Table 19). This measure represents the inverse of the sum of the shortest paths between the user and all other users in the network. It can be interpreted as a connectedness measure. For instance, teachers with high centrality might more efficiently distribute information to other teachers. *Betweenness centrality* is computed to describe teachers' "broker ability" in the selected communities (Figure 9, Table 19). This measure describes how often a user is part of the shortest path between two other users. It can be interpreted as an ability to connect more distant subnetworks. For instance, teachers with high broker ability might encourage other teachers to participate in the larger network. The visualizations (Figure 6-Figure 9) illustrate how teachers' placements in the teaching groupings vary depending on teacher's corresponding roles.

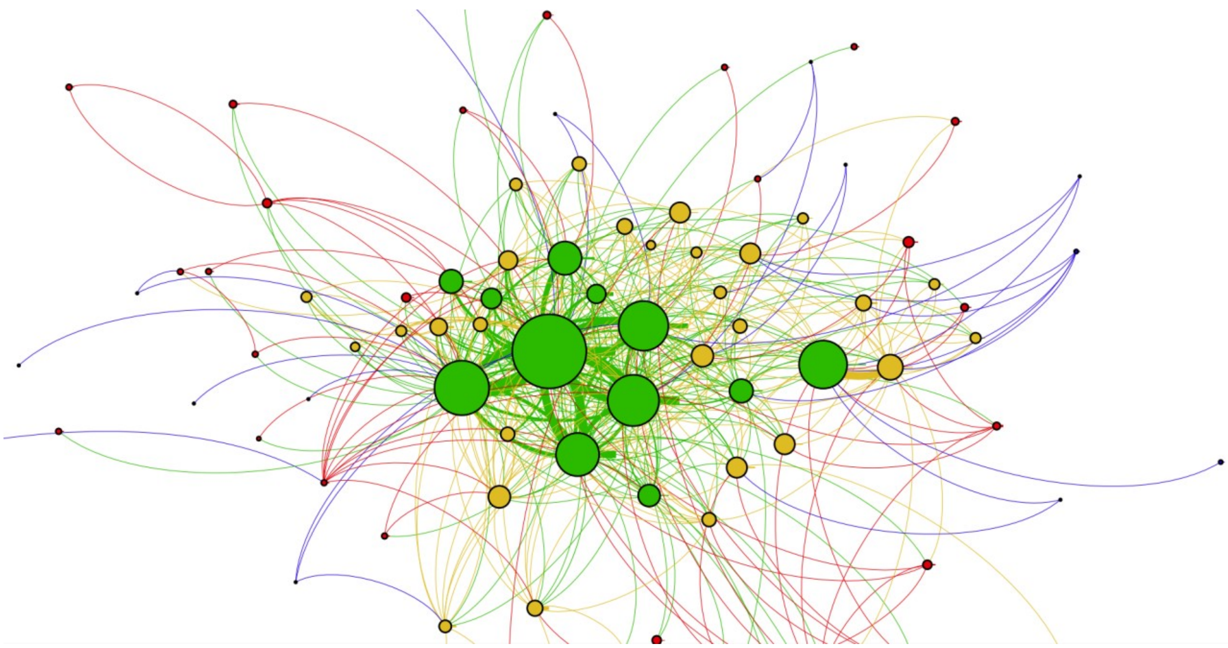

Figure 7. Visualization of eigenvector centrality classifications: no importance (<0.001; blue), low importance (0.001-0.150; red), medium importance (0.150-0.375; orange), high importance (0.375-1.000; green).

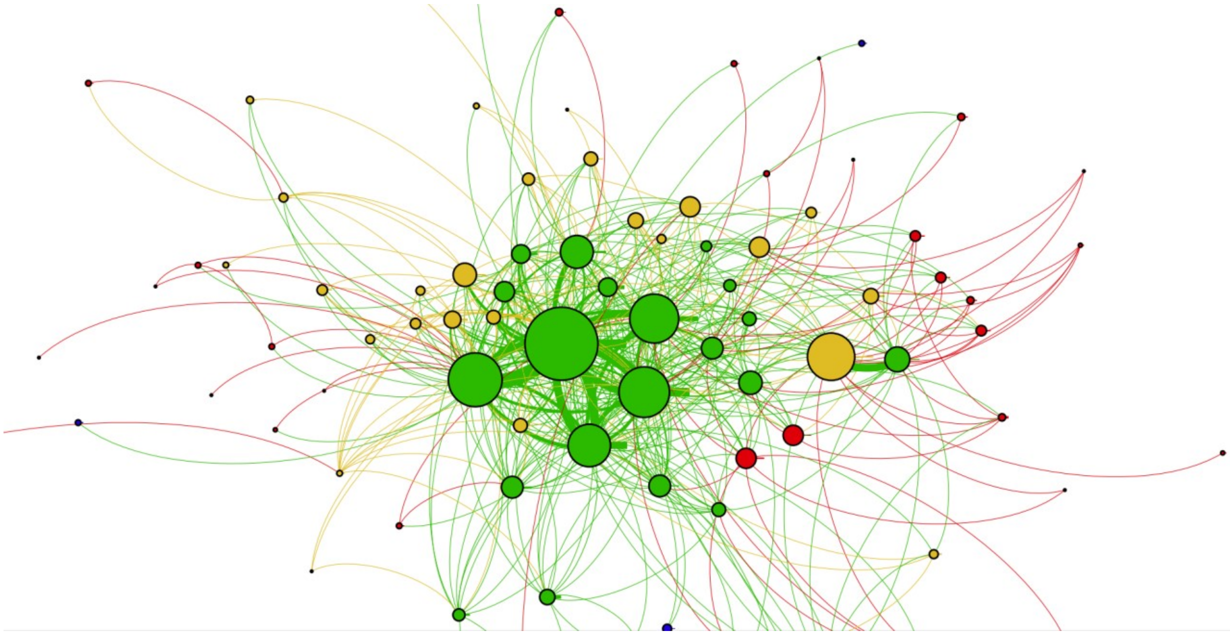

Figure 8. Visualization of closeness centrality classifications: no centrality (<0.001 and outside largest connected network; blue), low centrality (0.001-0.350; red), medium centrality (0.350-0.425; orange), and high centrality (>0.425; green).

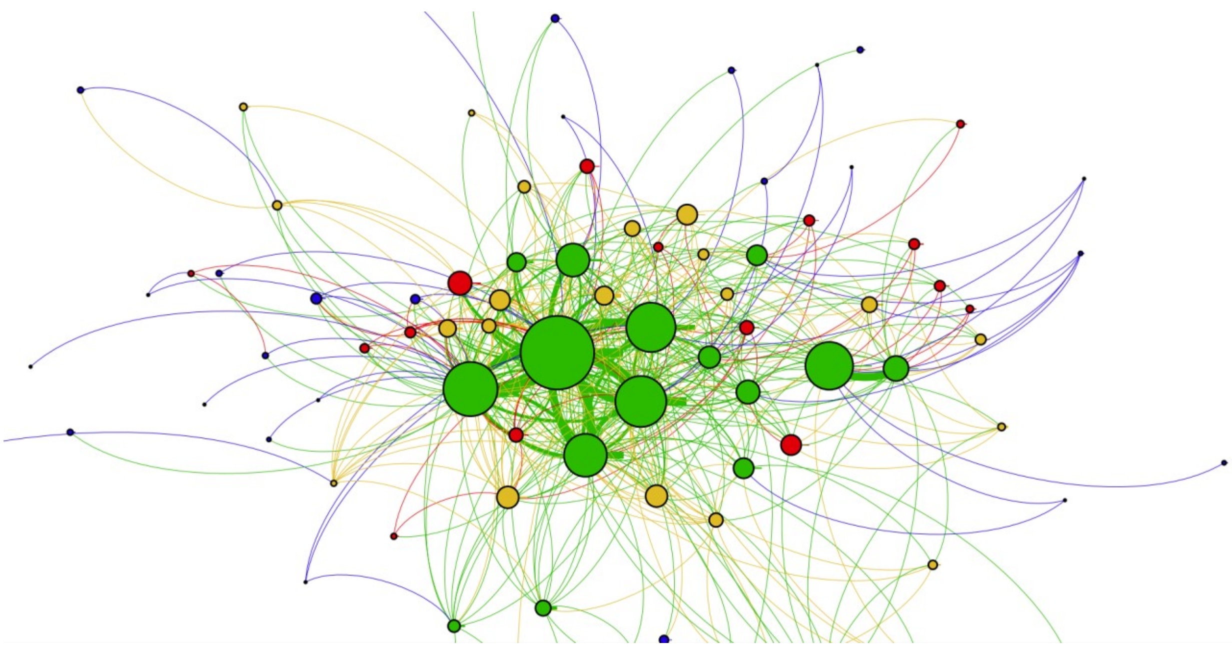

Figure 9. Visualization of betweenness centrality classifications: no broker ability (<0.1; blue), low broker ability (0.1-30; red), medium broker ability (30-300; orange), and high broker ability (>300; green).

Teachers are classified in four groups for each of the three measures (Figure 6-Figure 9, Table 19). Eigenvector and betweenness centrality classifications use thresholds based on numeric values of the corresponding social network analysis measures. However, the classification of closeness centrality slightly deviates from this approach. Nodes outside of the largest connected network are also assigned to the "no centrality" group. Table 19 provides descriptive statistics on the inferential social network analysis measures for teachers (i.e., this excludes schools administrators and representatives from professional organizations whose data was solely included to better represent teachers' relational position in the selected hashtag-based communities).

Table 19. Descriptive information of inferential SNA measures.

Variable name	N (%)	M (SD)
Teachers' influence groups		0.151 (0.202)
None	30 (32.26)	
Low	29 (31.18)	
Medium	24 (25.81)	
High	10 (10.75)	
Teachers' centrality groups		0.393 (0.304)
None	34 (36.51)	
Low	21 (22.58)	
Medium	20 (21.51)	
High	18 (19.35)	
Teachers' broker ability groups		267.60 (875.65)
None	16 (49.46)	
Low	13 (13.98)	
Medium	21 (22.58)	
High	13 (13.98)	

Analytical methods. To answer the *first research question*, teacher-level proportional odds ordered logistic regression models with robust standard errors are applied to analyze teachers' engagement patterns in the selected communities (e.g., Harrell, 2015). Dependent variables include ordinal variables that describe teachers belonging to teachers' influence (eigenvector centrality), centrality (closeness centrality), and broker ability (betweenness centrality) groups. Independent variables include variables that indicate the percentages of tweets in which teachers share AP Biology content knowledge (RQ 1.a), share resources (RQ 1.a, 1.b), seek information (RQ 1.b), and organize PD on Twitter (RQ 1.c). Covariates include variables that describe tweet content and teachers' community participation (Table 20).

To answer the *second research question*, contingency tables (tweet sentiment by tweet content) are used to illustrate tweet sentiment distributions across the different topics teachers discussed in the communities. Also, two-level fixed-effects hierarchical linear models (HLM) with Hubert-White sandwich estimators as robust standard errors are used to analyze associations of tweet sentiment with tweet engagement (e.g., Raudenbusch & Bryk, 2002). The dependent variable describes the sum of the number of retweets and likes a tweets receives. Multi-level modeling is necessary because tweets (level 1) are nested within teachers (level 2). Independent variables describe tweet sentiment. Covariates describe tweet content and tweet characteristic (tweet-level), as well as teachers' community participation (teacher-level) (Table 21).

Table 20. Variable list, research question 1.

RQ 1.a	RQ 1.b	RQ 1.c
	Dependent variables	
Teachers' influence	Teachers' centrality	Teachers' broker ability
	Independent variables	
AP Biology content[†,‡]	Seek information[†,‡]	Organize PD[†,‡]
Share resources[†,‡]	Share resources[†,‡]	
	Covariates	
Seek information[†,‡]	AP Biology content[†,‡]	AP Biology content[†,‡]
Organize PD[†,‡]	Organize PD[†,‡]	Share resources[†,‡]
Curriculum elements[†,‡]	Curriculum elements[†,‡]	Seek information[†,‡]
Labs[†,‡]	Labs[†,‡]	Curriculum elements[†,‡]
Assessments[†,‡]	Assessments[†,‡]	Labs[†,‡]
Lifespan[†]	Lifespan[†]	Assessments[†,‡]
Frequency[†]	Frequency[†]	Lifespan[†]
		Frequency[†]

Note. [†]: Grand-mean centered, [‡]: Teacher-level percentage.

Table 21. Variable list, research questions 2 and 3.

RQ 2	RQ 3
Dependent variable	*Dependent variable*
Tweet engagement	Lifespan†
Independent variable	*Independent variables*
Tweet sentiment ^{D}	AP Biology content†,‡
Tweet-level covariates (level 1)	Share resources†,‡
AP Biology content^{01}	Organize PD†,‡
Share resources^{01}	Curriculum elements†,‡
Seek information^{01}	Labs†,‡
Organize PD^{01}	Assessments†,‡
Curriculum elements^{01}	Positive sentiment†,‡
Labs^{01}	Negative sentiment†,‡
Assessments^{01}	Average: Retweets†
Mentions^{01}	Average: Likes†
Hashtags^{01}	Average: Mentions†
Links^{01}	Average: Hashtags†
Teacher-level covariates (level 2)	Average: Links†
Lifespan†	Frequency†
Frequency†	Teachers' influence ^{D}
Teachers' influence ^{D}	Teachers' centrality ^{D}
Teachers' centrality ^{D}	Teachers' broker ability ^{D}
Teachers' broker ability ^{D}	

Note. †: Grand-mean centered, ‡: Teacher-level percentage, ^{D}: Series of dummy variables, ^{01}: Dichotomous variable.

To answer the *third research question*, descriptive analyses and teacher-level ordinary least squares (OLS) multiple regression analysis with Hubert-White sandwich estimators as robust standard errors (Montgomery et al., 2012) are applied to explore teachers' temporal participation patterns. The dependent variable describes teachers' lifespan of participation in the online communities. Independent variables describe tweet content, tweet sentiment, quantitative tweet characteristics, and community participation characteristics (Table 21).

Assumptions of the modeling approaches are tested. For instance, teachers are uniquely distributed across teacher groups. Observations are independent from each other. Variance inflation factors confirm the absence of multicollinearity. Also, additional assumptions of the proportional odds logistic regression models are tested. For instance, the analytical sample includes more than 10 observations for each independent variable. Sensitivity analyses confirm stability of significance levels for changes in the threshold values for teacher group assignments.

Likelihood-ratio tests and AIC and BIC goodness-of-fit indices that compare proportional odds models to generalized ordered logistic regression models do not reject the parallel regression assumption. Furthermore, additional assumptions of OLS regression and (when appropriate) HLM models are tested. For instance, DFBETAs indicate that mean standard errors for all independent variables can be approximated as zero. Ramsey RESET tests indicate that residuals are not correlated with omitted independent variables. Leverage versus residual-squared plots indicate absence of influential cases. However, Breusch-Pagan/Cook-Weisberg tests and residual versus predictor plots identify homoscedasticity problems for some independent variables in OLS regression and HLM models. Similarly, univariate kernel density estimation plots and standardized normality plots indicate some normality of residuals problems in the OLS regression and HLM models. Both issues are addressed by including Huber-White sandwich estimators as robust standard errors.

Limitations. The most important limitations of this study are related to the data collection. For instance, generalization to overall teacher populations should be drawn with caution because schools could ask their most skilled and knowledgeable teachers to teach AP courses. In addition, the observed teachers might not represent the average AP Biology teacher population as two of the three selected hashtags are connected to one of the most intensive face-to-face PD activities, the NABT/BSCS AP Biology Leadership Academy. Also, Schlager and Fusco (2003) argue that online teacher learning is most effective if it is connected to face-to-face learning activities to extend professional conversation across multiple platforms. Thus, the participating teachers in the Twitter communities might be more motivated to engage in professional learning, might have a higher affinity to participate in online-based learning environments, might have higher self-efficacy, and could be more committed to teaching AP Biology courses aligned to the redesign AP curriculum than the average AP Biology teacher.

Another potential sampling and self-selection bias is that teachers who might have contributed tweets with primarily negative sentiments might have felt discouraged to participate in the communities. Similarly, if the communities were mostly negative, teachers might have chosen not to participate in the first place. However, this bias might be small because Twitter users often express their dissent in other topics such as politics or consumer product branding. For instance, Twitter has been used to express protest with respect to political elections and democratic activism (e.g., Small, 2011). Similarly, Jansen, Zhang, Sobel, and Chowdury (2009) analysis of 150,000 tweets about brands finds that roughly a third of all tweets are critical of the product or company. With respect to the AP redesign, negative sentiments might have been more prominent if teachers' felt a larger sense of disagreement with core elements of the science curriculum reform. A further threat to validity is that this study solely relies on publicly available data. Learning experiences of lurkers are not captured although lurkers fulfill important roles in the communities and might highly benefit from the visible interactions of posters (e.g., Edelmann, 2013; Fischer, Frumin, et al., 2016; Preece et al., 2004).

Potential threats to reliability are related to the format of the collected data. While Twitter allows users to attach pictures and video to their tweets, this study solely focuses on the text-based tweet components potentially omitting additional information that might lead to different tweet content or sentiment assignments. Additionally, user content that was deleted prior to the data collection, as well as private communication between users are unavailable for this data collection. For instance, teachers worried about repercussions of negative tweets might avoid a public display of their statements. Therefore, some components relevant to teacher learning on

Twitter might have been omitted. Similarly, other potentially important variables such as attitudes towards PD and Twitter, self-efficacy, prior content knowledge, school affluence, or administrative support that might influence the examined relationships as either extraneous or confounding variables are not included in the models.

Results

Hierarchies in participation structures on Twitter. Teachers' classifications in the groups based on influence, centrality, and broker ability ratings are examined to explore whether leadership structures on Twitter mirror or contrast to more hierarchically organized traditional PD activities in which designated leaders contribute and distribute most content, lead discussion, and organize the PD activities.

Teachers' sharing of content knowledge helps predict teachers' belonging to influence-based teacher groups, whereas teachers' sharing of resources does not provide a significant contribution (RQ 1.a, Table 22). A ten percent increase in teachers' tweets relating to AP Biology content knowledge is associated with a 2.7% decrease in the odds of teachers belonging to higher influence teacher groups, holding everything else constant. This is in contrast to more traditional PD activities in which persons who share content knowledge or resources might commonly be perceived as leaders.

Teachers' information seeking behavior does not significantly predict teachers' belonging to centrality-based teacher groups, whereas teachers' resources sharing behavior serves as such a predictor (RQ 1.b, Table 22). A ten percent increase in tweets that share resources is associated with a 2.4% decrease in the odds of teachers belonging to higher centrality teacher groups, holding everything else constant. These findings support a perspective on Twitter in which responsibilities for sharing resources are distributed among users such that hierarchical distinctions between learners and 'experts' are reduced. This contrasts more traditional PD activities in which PD leaders, who could be viewed as the most central persons, potentially share most resources.

Teachers' engagement in the organization of PD on Twitter predicts teacher classifications in broker ability based groups (RQ 1.c, Table 22). A ten percent increase in teachers' tweets related to the organization of PD activities on Twitter is associated with a 1.6% decrease in the odds of teachers belonging to higher broker ability teacher groups, holding everything else constant. This provides support for a perspective on Twitter in which persons organizing and recruiting new participants do not serve as the only interaction partners for new community members. Instead, new community members have instant access to all resources and potentially feel more confident to interact with other community members. This could be described as a removal of a participation barrier – similar to barriers such as costs, geographic location, and time – that teachers might encounter in more traditional PD activities.

Twitter as an affective support system. The topics teachers discuss in the selected Twitter communities have more often positive than negative tweet sentiments. Nonetheless, tweets are mostly not characterized by exclusively positive or negative sentiments. The topics teachers' most often frame positively are sharing resources (28.6 %), organizing PD activities on Twitter (24.4 %), and laboratory investigations (24.0 %) (RQ 2.a, Table 23). This provides a first indication that professional learning on Twitter is approached from a positive perspective and might function as an affective support system.

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Table 22. Ordinal regression analyses with robust standard errors predicting classifications of teacher influence (model 1, eigenvector centrality), centrality (model 2, closeness centrality), and broker ability (model 3, betweenness centrality).

	Model 1: Teachers' influence			Model 2: Teachers' centrality			Model 3: Teachers' broker ability		
	b	*OR*	*z*	*b*	*OR*	*z*	*b*	*OR*	*z*
Independent tweet content variables (10% increments)									
AP Biology content (%)	-0.277*	0.973*	-2.24	-0.350~	0.966~	-1.75	-0.154	0.985	-1.55
Share resources (%)	-0.102	0.990	-1.42	-0.239**	0.976**	-2.75	-0.170*	0.983*	-2.15
Seek information (%)	0.068	1.007	0.67	-0.011	0.999	-0.08	-0.048	0.995	-0.42
Organize PD (%)	-0.050	0.995	-0.75	0.025	1.002	0.38	-0.166*	0.984*	-2.38
Tweet content covariates (10% increments)									
Curriculum elements (%)	0.063	1.006	0.27	-0.180	0.982	-0.88	0.140	1.014	0.76
Labs (%)	-0.136	0.986	-0.87	0.057	1.006	0.27	-0.202	0.980	-1.26
Assessments (%)	0.366	1.037	0.81	0.593***	1.061***	4.32	0.198	1.020	1.50
Community participation covariates									
Lifespan (in 10 days)	0.061***	1.006***	5.52	0.094***	1.009***	4.67	0.115***	1.012***	4.16
Tweets/day	0.215**	1.240**	3.17	0.279***	1.321***	3.89	0.094	1.099	1.29
Intercepts									
Cutoff 1	-1.177			-1.055			-0.502		
Cutoff 2	0.858			0.700			0.628		
Cutoff 3	3.182			2.715			3.896		
McFadden's R^2	0.240			0.337			0.379		

Note. ~p < 0.10, *p < 0.05, **p < 0.01, ***p < 0.001, N = 93.

Table 23. Contingency table on tweet sentiment with content measures.

	Negative sentiment [%]	Positive sentiment [%]	Not exclusively positive or negative [%]
AP Biology content	3.82	22.90	73.28
Share resources	1.35	28.62	70.03
Seek information	5.60	10.00	84.40
Organize PD	1.19	24.40	74.40
Curriculum elements	6.40	13.60	80.00
Labs	8.57	24.00	67.43
Assessments	11.76	14.44	73.80

Note. N_{tweet} = 2,040.

Direct associations of tweet sentiment with tweet engagement (i.e., number of retweets and likes) are examined to explore this initial finding in more depth (RQ 2.b, **Error! Not a valid bookmark self-reference.**). Tweet engagement can be interpreted as a measure that describes the ability to distribute information within teachers' communities and beyond. Thus, tweets with high tweet engagement are more likely to shape interaction patterns and knowledge gains.

Table 24. Two-level fixed-effect HLMs with robust standard errors.

	Model 1		Model 2		Model 3	
Tweet engagement	*b*	*SE*	*b*	*SE*	*b*	*SE*
Tweet-level (level 1)						
Tweet sentiment (vs. not exclusively positive or negative)						
Positive					0.444**	0.157
Negative					-0.196	0.121
Tweet content						
AP Biology content			0.047	0.170	0.091	0.176
Share resources			0.122	0.262	0.077	0.253
Seek information			-0.643**	0.240	-0.540*	0.225
Organize PD			-0.040	0.186	-0.020	0.188
Curriculum elements			-0.148	0.207	-0.102	0.208
Labs			-0.015	0.139	0.037	0.131
Assessments			0.142	0.220	0.204	0.224
Tweet characteristics						
Mentions			-0.029	0.055	-0.015	0.055
Hashtags			0.531***	0.069	0.531***	0.068
Links			1.019**	0.348	1.092**	0.355
Teacher-level (level 2)						
Intercept	0.646	0.449	0.308	0.518	0.193	0.515
Community participation						
Lifespan (in 10 days)	0.009	0.009	0.002	0.010	0.001	0.010
Tweets/day	-0.041	0.054	-0.037	0.056	-0.031	0.055
Teachers' influence (vs. high)						
None	0.147	0.832	-0.228	0.891	-0.317	0.887
Low	0.925	0.590	0.596	0.624	0.540	0.604
Medium	0.470*	0.229	0.308	0.238	0.261	0.232
Teachers' centrality (vs. high)						
None	1.108~	0.667	0.259	0.765	0.351	0.753
Low	0.910	0.696	0.614	0.695	0.680	0.681
Medium	0.081	0.425	0.051	0.434	0.125	0.427
Teachers' broker ability (vs. high)						
None	-0.738	0.808	-0.590	0.892	-0.629	0.885
Low	-0.421	0.726	-0.473	0.760	-0.582	0.740
Medium	-0.499	0.567	-0.649	0.590	-0.679	0.576
χ^2	21.43		173.30		23.64	
df	11		10		2	
p	0.029		<0.001		<0.001	

Note. ~p < 0.10, *p < 0.05, **p < 0.01, ***p < 0.001; Likelihood-ratio tests use models without robust standard errors; N_{level1} = 2,040, N_{level2} = 93.

Tweet-level variables account for 77% and teacher-level variables account for 23% of the variance in tweet engagement (ICC = 0.23). This exceeds common ranges of ICC values in social science research (0.05-0.20; Peugh, 2010) and confirms the appropriateness of multi-level approaches. Positive tweet sentiment is significantly associated with a 0.44 increase in tweet engagement, $b = 0.44$, $z = 2.83$, $p < 0.01$, compared to tweets with not exclusively positive or negative sentiments. In contrast, negative tweet sentiment is not significantly associated with changes in tweet engagement, $b = -0.20$, $z = -1.62$, $p =$ n.s. This provides support for perspectives that Twitter can provide a positive and supportive frame for teacher learning

Temporal engagement patterns. An analysis of temporal engagement patterns in the Twitter communities indicates that both lifespan and frequency of participation highly varies across teachers. Some teachers choose to participate for relative short durations whereas other teachers substantially exceed timespans of more traditional PD activities (Figure 10).

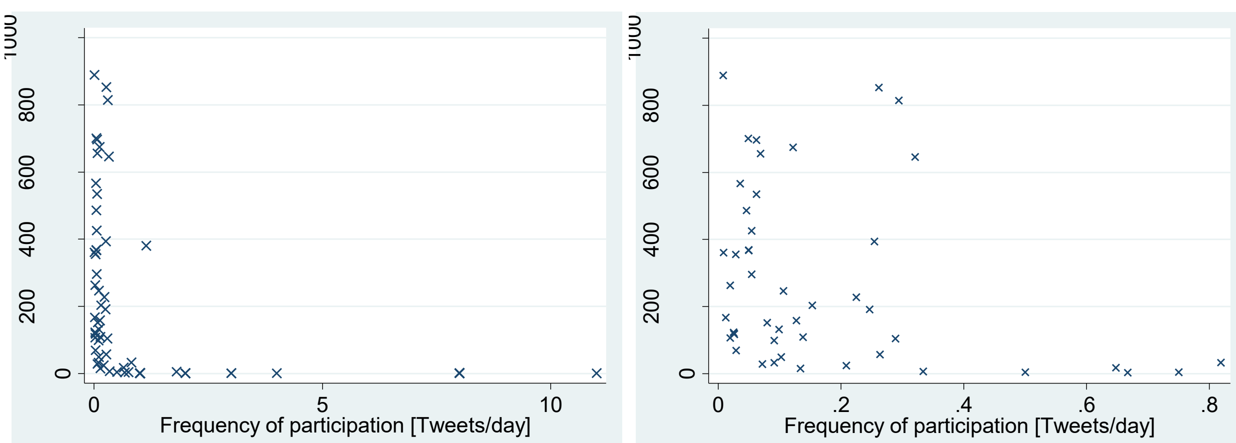

Figure 10. Scatter plots of teachers' lifespan and frequency of community participation; full sample (left), frequency < 1 (right).

Teachers' community lifespan serves as a strong predictor for all analyzed forms of leadership roles (teachers' influence, centrality, and broker ability) in the communities (Table 22). However, teachers' community lifespan is uncorrelated with their frequency of participation for teachers participating in the communities for longer than a week, $r = -0.08$, $p > 0.05$ (Figure 10). In particular, teachers with high Twitter community lifespans meet duration thresholds that Darling-Hammond et al. (2009) and Desimone (2009) characterize as preconditions for effective PD, thus, fulfilling Desimone's (2009) high-quality PD characteristics of 'duration.'

Significant direct associations are not found between teachers' community lifespan and most tweet content, quantitative tweet characteristics, and community participation variables (RQ 3b, Table 25). Nevertheless, factors that significantly contribute to teachers' community lifespan, as well as factors whose contribution approaches significance (not achieving significance is likely due to the small sample size), provide insights in teachers' temporal participation patterns. For instance, the relationships of the percentage of tweets sharing AP Biology content knowledge, as well as the percentage of positive tweets with teachers' community lifespan approach significance. A ten percent increase of tweets sharing AP Biology content knowledge is associated with an approximate eleven day community lifespan increase, $b = 10.59$, $t = 1.82$, $p < 0.10$. A ten percent increase in tweets with positive sentiment is associated with an approximate eight day community lifespan increase, $b = 7.87$, $t = 1.93$, $p < 0.10$. The implication that positive-oriented content creation lead to a longer participation duration promotes perspectives that view Twitter as a supportive environment for teachers. Regarding quantitative tweet characteristics, both average numbers of mentions and hashtags significantly contribute to teachers' community lifespan. Mentioning on average one additional user per tweet is significantly associated with an approximate 36 day decrease of teachers' community lifespan, $b = -35.67$, $t = -2.22$, $p < 0.05$, and including on average one additional hashtag per tweet is associated with an approximate 57 day increase of teachers' community lifespan, $b = 57.14$, $t = 2.07$, $p < 0.05$. These results describe that conversational practices on both the micro-level (mentioning) and the macro-level (hashtags) are related to temporal participation pattern. This indicates that Twitter allows for different interaction patterns to fit teachers' individual contexts, professional needs, and professional learning preferences, which contrasts 'one-size-fits-all' approaches.

Table 25. Linear regression analysis with robust standard errors.

Lifespan (days)	*b*	*SE*	*t*
Intercept	461.786***	67.811	6.81
Tweet content (10% increments)			
AP Biology content (%)	10.587~	5.806	1.82
Share resources (%)	5.330	5.491	0.97
Seek information (%)	5.052	10.379	0.49
Organize PD (%)	0.806	5.274	0.15
Curriculum elements (%)	2.465	9.198	0.27
Labs (%)	1.108	8.573	0.13
Assessments (%)	-12.932	7.793	-1.66
Tweet sentiment (vs. not exclusively positive or negative; 10% increments)			
Positive sentiment (%)	7.869~	4.074	1.93
Negative sentiment (%)	3.220	13.679	0.24
Tweet characteristics			
Average: Retweets	-37.933	35.849	-1.06
Average: Likes	24.053	15.750	1.53
Average: Mentions	-35.671*	16.058	-2.22
Average: Hashtags	57.144*	27.630	2.07
Average: Links	-30.263	51.461	-0.59
Community participation			
Teachers' influence (vs. high)			
None	15.672	75.987	0.21
Low	10.725	70.051	0.15
Medium	-46.355	59.330	-0.78
Teachers' centrality (vs. high)			
None	-212.256*	79.742	-2.66
Low	-92.462	72.998	-1.27
Medium	-83.195	66.972	-1.24
Teachers' broker ability (vs. high)			
None	-439.748***	84.978	-5.17
Low	-428.342***	75.000	-5.71
Medium	-285.503***	64.540	-4.42
R^2	0.736		

Note. ~p < 0.10, *p < 0.05, **p < 0.01, ***p < 0.001, N = 93.

Discussion

Scholarly significance. This observational mixed-methods study contributes to the in-service secondary science teacher education research base in multiple ways. The context of the AP redesign, a large-scale, nationwide, top-down curriculum and examination change incentives AP teachers to engage in professional learning to prepare for this change. Therefore, findings might generalize to other large-scale curriculum reforms such as the NGSS or the Common Core State Standards Initiative. This study constitutes the first empirical study that analyzes teachers' engagement in microblogging during a nationwide curriculum reform in the sciences. Additionally, this study provides insights about how teacher participation in online communities might extend more traditional professional learning activities. Also, it provides a theoretical contribution by providing another example of a PD environment that adheres to selected high-quality PD design characteristics. Furthermore, from a methodological perspective, this study extends the current mostly descriptive and qualitative-oriented research base on microblogging for professional learning by analyzing teachers' engagement in microblogging using educational data mining, social network analysis, and other more quantitative-oriented approaches.

Future work. Future studies could gather more in-depth information on how teachers perceive Twitter to complement their professional learning. For instance, one set of follow-up studies might survey or interview teachers of the analyzed communities. Selection could follow a purposeful extreme case sampling approach using the teacher classifications in community participation groups. A second set of follow-up studies could target lurkers in the Twitter communities to better understand their professional learning benefits. A third set of follow-up studies could explore the generalizability of this study's findings. Potential comparison groups could include AP Biology Twitter communities that are focused on specific elements of the AP curriculum elements, non-AP Biology teacher Twitter communities, or teacher communities that allow for pre- and post-AP redesign comparisons. A fourth set of follow-up studies could shift the current emphasis of conversational practices on the macro-level (hashtag-based communities), as described by Bruns and Moe (2013), to meso-level analysis of selected teachers' ego-networks to explore how learning occurs in teachers' tweets by analyzing tweet sequences and follower-followee structures. An interdisciplinary follow-up application in the intersection of cognitive science and natural language processing would be to automate the detection (and basic analysis) of such learning processes to analyze teacher learning in social network communities at scale.

Implications and conclusion. This study offers insights on teachers' use of Twitter as a novel form for professional learning and how it might complement more traditional PD activities. The three most important conclusions from this study are the following:

First, teacher learning on Twitter does not follow hierarchically leadership and participation structures. In contrast to more traditional PD activities, teachers who mostly share content knowledge are less likely to be the most influential teachers, teachers who frequently share resources are less likely to be the most central teachers, and teachers who mostly organize PD activities on Twitter are less likely to be the most connected teachers in the communities. This supports perspectives that view Twitter as a more open, democratic, and collaborative environment (e.g., Carpenter & Krutka, 2014; Lord & Lomicka, 2014; Wesely, 2013).

Second, professional learning on Twitter is positively framed by the teachers participating in the online communities. Teachers are more likely to be exposed to tweets with a positive sentiment instead of a negative sentiment. Also, the more positive tweets teachers post, the longer their typical participation lifespan in the communities. Furthermore, tweets with positive sentiment receive significantly more likes and retweets. This indicates that Twitter can provide a positive and supportive environment for teachers. The value of teachers participating in support communities to potentially battle isolation in their individual school contexts cannot be underestimated, for instance, contributing to improved mental health, increased performance, and reduced turnover rates (e.g., Dodor et al., 2010).

Third, teacher learning on Twitter is adaptive to teachers' needs and preferences with respect to teachers' temporal participation patterns. In contrast to traditional PD activities with fixed durations, Twitter allows teachers to engage in flexible temporal participation patterns. While some teachers have all their interactions with Twitter communities 'just-in-time' within one day or week, other teachers continuously contribute to the communities over extended periods of time exceeding duration thresholds for effective PD participation (e.g., Darling-Hammond et al., 2009; Desimone, 2009). These flexible participation patterns support perspectives that view Twitter as affording a personalization of professional learning with the potential to engage in virtual forms of 'collective participation' (e.g., Desimone, 2009) in virtual communities of practice opposed to "one-size-fits-all" approaches (e.g., Carpenter & Krutka, 2015; Ebner et al., 2010; Wesely, 2013; Zhao & Rosson, 2009).

In conclusion, this study aims to analyze a new form of professional learning that might contribute to a transformation of current educational paradigms. The data suggests that professional learning in microblogging environments has the potential to both adhere to standards of high-quality PD activities and to complement hierarchically-structured, more traditional forms of professional learning. Thus, educational policy makers and school leaders should feel empowered to encourage teachers to engage in microblogging for professional learning in addition to other more traditional professional learning outlets.

Chapter Five – Conclusion

The three studies in this multi-manuscript dissertation offer a unique perspective that advances the in-service secondary science teacher education research base, applying a multitude of quantitative research methodologies. Situated in the context of the large-scale, nationwide, and top-down curriculum and examination reform of the AP science program, the findings presented in this dissertation might also be generalizable to other curriculum reforms such as the NGSS (NGSS Lead States, 2013) or the CCSS (Common Core State Standards Initiative, 2010a, 2010b). This dissertation aims to provide recommendations for changes in the educational landscape to guide transformations of professional learning activities for teachers in times of technological advancements, to validate existing research frameworks for the effects of PD, and to narrow opportunity gaps ultimately striving to increase overall student learning and achievement. The main contributions from this dissertation are the following:

The first dissertation study indicates that proactive educational policies that increase school funding, teacher quality, and teacher partipation in selected PD activities can help narrow income achievement gaps and foster educational equity for students in low-SES schools. While identifying the importance of school context for teachers and students is not surprising, ascertaining positive significant associations of districts' per-student funding allocations and the length of the school year with students' performance gains on high-stakes examinations critical implications for college course-taking is an extension of prior literature in this area (e.g., Roegman & Hatch, 2016). Also, the direct relationship between teachers' knowledge and experience in low-SES schools with students' AP performance gains emphasizes the need to support efforts that place highly qualified teachers in high poverty schools to ensure equitable access to high quality learning opportunities for students that are disadvantaged (e.g., Isenberg et al., 2013). Furthermore, the finding that selected PD actitivities (i.e., PD that teachers rate as effective help for their classroom instruction, unconventional face-to-face PD activities [e.g., teacher-initiated meetings, mentoring or coaching activities, and conference participations]) can improve student achievement supports previous research that emphasizes the importance of PD to be coherent with respect to what teachers are asked to do in their classrooms (e.g., Penuel et al., 2007).

The second dissertation study indicates that PD participation can help teachers to change their classroom teaching. However, instructional changes that are induced by teachers' PD participation might not always lead to increases in student achievement. The findings validate selected relationships described in Desimone's (2009) framework for studying the effects of PD. Teaching and learning are situated within and influenced by contextual factors. PD participation can produce teachers' knowledge and skill growth and foster changes in classroom teaching. However, the absence of a strong relationship of the observed teaching practice elements with student scores might serve as an alternative explanation why recent PD effectiveness studies do not detect large direct effects of PD participation with student performance (e.g., Arens et al., 2012; Bos et al., 2012; Garet et al., 2008, 2011; Jacob & McGovern, 2015). Therefore, these findings demonstrate the ongoing need for research that identifies effective teaching practices that lead to improved student learning and achievement.

The third dissertation study indicates that teacher PD in collaborative online microblogging communities can adhere to design characteristics of high-quality PD and can have the potential to complement more traditional PD activities. The non-hierarchical leadership and participation structures support views of Twitter as a more open, democratic, and collaborative environment than more hierarchically-structured traditional PD activities affording teachers to engage in virtual forms of 'collective participation' in virtual communities of practice (e.g., Lord & Lomicka, 2014; Wesely, 2013). Also, teacher learning on Twitter is adaptive to teachers' needs and preferences and allows teachers to engage in flexible temporal participation patterns affording teachers to personalize their professional learning experience, which is in contrast to common "one-size-fits-all" approaches. Furthermore, teachers' interactions on Twitter for professional learning mostly facilitate positive and supportive environments which support teachers to reduce potential perceived isolation in local school contexts and, in turn, could make a contribution to reduced turnover rates, improved mental health, and increased teaching performance (e.g., Dodor et al., 2010).

Future work. This dissertation motivates future research in a range of directions. From a methodological perspective, future research could go beyond the "process-product logic" (Opfer & Pedder, 2011, p. 384) to emphasize the multi-level, interdependent, and dynamic relationships of school context, teacher learning, classroom instruction, and student learning and achievement from a complexity theory lens (Byrne & Callaghan, 2014; Cochran-Smith et al., 2014; Opfer & Pedder, 2011). Additionally, instead of mostly assuming linear relationships, some associations might be better described through polynomial, exponential, or other functional relationships. Furthermore, interaction, mediating, and moderating effects could also be investigated.

In terms of data sources available to this dissertation, additional data on teachers' classroom practices would be useful to triangulate information derived from teacher self-reports on the web-based surveys or statements in the microblogging communities to better understand and validate the observed relationships. However, given the nationwide scope and scale of this project, collecting such data would likely be limited to selected case studies. For instance, an interesting follow-up to the microblogging study might be to interview teachers. Such teachers could be selected using a purposeful extreme case sampling approach. Future research could investigate how teachers who mostly engage in lurking behavior in the microblogging communities benefit from their participation and whether lurking in online communities also has the potential of complementing more traditional PD activities.

Follow-up studies based on the data sources already available for this multi-manuscript dissertation afford numerous potentially insightful directions. For instance, instead of using students' aggregated final AP scores as the primary outcome measure, AP subscale score data (e.g., percentage of multiple choice questions correct for a specific content or practice type) could be used to better discern the impact of certain PD activities and specific instructional practices on selected components of the AP examinations with a greater precision. With respect to the Twitter study, teachers' content-based statements could be analyzed regarding their scientific accurateness as the absence of hierarchical structures and an authoritative corrective could lead to inadvertent promotion of scientifically incorrect content which, in turn, could potentially harm student learning and achievement.

More generally, this dissertation provides support for calls for research that are targeted towards helping teachers with their selection of PD activities, furthering insights on novel technology-enhanced PD activities that might complement more traditional PD activities, and contributing to the identification of teaching practices that effectively increase student learning and performance in our shared mission of providing better support for students on their path through the U.S. education system.

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Appendix

The appendix includes the web-based survey sent to all AP Biology teachers in 2015 who did not respond to previous web-based surveys of the NSF-funded project. This survey is exemplary for all other web-based surveys of this project, although some survey questions and sections varied across disciplines and years.

AP Biology Survey - 2015 - NEW teachers

Dear AP Biology Teacher:
This is a survey about your professional development activities and how you prepared for this year's redesigned AP Biology course and exam. This survey is part of a National Science Foundation (NSF) supported research study of how AP teachers are preparing for the redesign of the AP Biology curriculum. Your participation will help us understand how professional development can better meet teachers' needs, particularly when adjusting to large-scale changes in curriculum.

Different teachers have different needs. We want to hear from ALL teachers. Make sure your voice is heard! To thank you for completing the survey, we will offer all participants a certificate of appreciation from the College Board (that can be shared with your school administrator), as well as the following opportunities and incentives:

All participants will be invited to participate in a live presentation by the Chief Reader of the AP Biology exam. The Chief Reader will review major lessons learned while grading the AP Biology exams in June 2015.

All participants will receive a draft of the official free response scoring guidelines for the 2015 AP Biology exam. These rubrics will be distributed before the official version is published.

All participants will have a chance to win $100. Fifty participants will be selected at random, and winners will be selected every day. The sooner you complete the survey, the more chances you have of winning. All winners will be notified after July 15, 2015.

We ask that you complete this survey by Monday, June 22. If you are unable to finish the survey in one sitting, you may continue it later by clicking on the link that we sent to you via email. Please save your email, and do not share that link because it is unique to you. We expect that this survey will take you between 20 and 30 minutes to complete.

Sincerely,
Arthur Eisenkraft
Distinguished Professor of Science Education, University of Massachusetts at Boston Chair, Science Academic Advisory Council, College Board

Are you using a smartphone or small tablet to take this survey? Note that some of the questions on this survey may not display properly on the small screens of mobile browsers. If you wait to take the survey on a laptop or desktop computer, your overall experience will be better.

Benefits and Risks
It is hoped that through your participation, you will find value in helping us to better understand effective professional development so that different providers can support more effective professional development in the future. The risk involved in participating in this study is minimal.

Confidentiality
All data obtained from participants will be stored in a secure database, kept confidential and will only be reported in the aggregate (by reporting only combined results and never reporting individual cases or data). No one other than the researchers will have access to it. The College Board will not have access to your individual responses.

Participation
Participation in this survey is completely voluntary. You may withdraw by exiting the survey at any time.

Questions about the Research
If you have questions regarding this study, you may contact arthur.eisenkraft@umb.edu or awheelock@collegeboard.org.

Questions about your Rights as Research Participants
If you have questions about your rights as a survey participant, you may contact the UMass Boston Institutional Review Board at 617-287-5374 or kristen.kenney@umb.edu. Please reference study 2013067.

Please indicate below whether or not you consent to participate in this survey:
- ❍ YES, I consent to participate in this survey (please click the “Continue” button below to continue the survey) (1)
- ❍ NO, I do not consent to participate (please click the “Continue” button below to exit the survey) (0)

What Professional Development Did you Participate In?

There are many different ways that teachers might prepare for teaching AP science. Below, please indicate which of the following resources, informal professional development (PD) activities, or formal PD activities you used as part of your preparation to teach the revised AP curriculum within the past year (since the conclusion of the prior school year in June, 2014).

1. Face to Face or In-Person PD Options Did you participate in any of the following face-to-face or in-person PD activities as part of preparation or support for teaching your AP course during the past year? (Please check all that apply)

- ❑ AP Summer Institute (4-5 days), from the College Board (1)
- ❑ AP Biology Workshop (1 day), from the College Board (2)
- ❑ AP Biology: Transitioning to Inquiry-based Labs workshop (1 day), from the College Board (3)
- ❑ Day with an AP Reader (1 day), from the College Board (14)
- ❑ Laying the Foundation (4-5 days) offered by NMSI (15)
- ❑ BSCS Leadership Academy (4-5 days) offered by NMSI and NABT (16)
- ❑ A district, regional, local college, or teacher-initiated meeting (6)
- ❑ Mentoring or coaching one-on-one or with other teachers (7)
- ❑ Conferences or conference sessions (8)
- ❑ Were you an AP Biology exam reader (in the past year)? (9)
- ❑ Were you an AP Biology Consultant (in the past year)? (10)
- ❑ Other (11) ____________________

2. Self-Paced Online PD Options Did you participate in any self-paced online PD courses as part of preparation or support for teaching your AP course during the past year? (Please check all that apply)

- ❑ Transitioning to Inquiry-Based Labs online PD (6 hours, self-paced), from the College Board (1)
- ❑ Introduction to AP Biology online PD (6 hours, self-paced), from the College Board (2)
- ❑ AP Insight, from the College Board (11)
- ❑ Other online PD courses? (4) ____________________

3. Online Communities or Discussion Boards Did you participate in any online communities or discussion boards as part of preparation or support for teaching your AP course during the past year? (Please check all that apply)

- ❑ AP Teacher Community (provided by the College Board) (1)
- ❑ National Science Teachers' Association (NSTA) online community (2)
- ❑ Other online communities? (3) ____________________

4. Published or Print Materials Did you use any of the following published, print, or downloaded materials on your own as part of preparation or support for teaching your AP course in the past year? (Please check all that apply)

- ❑ The AP Course and Exam Description from the College Board (1)
- ❑ The AP Lab Manual from the College Board (2)
- ❑ Practice AP Exams from the College Board (10)
- ❑ My textbook teacher guide and related materials (3)

5. Other Kinds of Materials Did you use any of the following other materials as part of preparation or support for teaching your AP course in the past year? (Please check all that apply)

- ❑ Instructional materials developed by colleagues, including handouts, pacing guides, labs, tests and quizzes, etc. (1)
- ❑ Articles from magazines or journals (2)
- ❑ Video resources, such as how-to videos for lab equipment or procedures or video guides to teaching techniques, etc. (NOT including the "Exploring Atomic Structure with PES Data" video from AP Central) (3)
- ❑ Online or computer-based simulations (such as PhET) (4)
- ❑ Other (5) ____________________

6. No Professional Development If you did not engage in any PD activities during the past year to help you prepare for teaching the revised AP curriculum, please check the box below.

- ❑ I did not participate in any PD activities related to the teaching of my AP course in the past year. (1)

Confirm your Professional Development Activity Selections

7. On the following screens, we ask a few follow-up questions about your experience with each of the PD activities you checked to indicate that they were a part of your preparation for teaching your AP science course in the past year (since the conclusion of the prior school year in June, 2014). If you selected "Other" in any category, we are not displaying that here and you will not be asked follow-up questions about that PD activity. If you would like to change any of your selections, please use the "Change my Selections" button at the bottom of this page to return to the PD selection screen.

- ❍ AP Summer Institute (4-5 days) from the College Board (7)
- ❍ AP Biology Workshop (1 day) from the College Board (8)
- ❍ Transitioning to Inquiry-based Labs workshop (1 day) from the College Board (9)
- ❍ Day with an AP Reader (1 day) from the College Board (39)
- ❍ Laying the Foundation (4-5 days) offered by NMSI (40)
- ❍ BSCS Leadership Academy (4-5 days) offered by BSCS and NABT (41)
- ❍ A district, regional, local college, or teacher-initiated meeting (13)
- ❍ Mentoring or coaching one-on-one or with other teachers (14)
- ❍ Conferences or conference sessions (15)
- ❍ Were you an AP Biology exam reader (in the past year)? (23)
- ❍ Were you an AP Biology Consultant (in the past year)? (24)
- ❍ Transitioning to Inquiry-Based Labs online PD (6 hours), from the College Board (16)
- ❍ Overview of AP Biology online PD (6 hours), from the College Board (17)
- ❍ AP Insight, from the College Board (66)
- ❍ AP Teacher Community (provided by the College Board) (18)
- ❍ National Science Teachers' Association (NSTA) online community (19)
- ❍ The AP Curriculum Guide and Exam Description from the College Board (1)
- ❍ The AP Lab Manual from the College Board (4)
- ❍ Practice AP Exams from the College Board (59)
- ❍ My textbook teacher guide and related materials (3)
- ❍ Instructional materials developed by colleagues, including handouts, pacing guides, labs, tests and quizzes, etc. (2)
- ❍ Articles from magazines or journals (5)
- ❍ Video resources (6)
- ❍ Online or computer-based simulations (such as PhET) (37)
- ❍ I did not participate in any professional development related to my AP science course (20)

Note: Once you confirm your PD selections by clicking “continue” below, you will not be able to go back and change them.

You have finished 1 out of 9 sections in this survey. Thank you!

The following questions refer to the **AP Summer Institute (4-5 days)** provided by the College Board as PD for your AP Science course.

Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with the AP Summer Institute PD activity.

8. To what extent did the AP Summer Institute include passive and/or active learning experiences? Active learning might include hands-on activities or small-group activities. More passive forms of PD might consist of lectures or presentations.
❍ Almost all passive learning (1)
❍ (2)
❍ Equal mix of passive and active learning (3)
❍ (4)
❍ Almost all active learning (5)

9. Was the AP Summer Institute responsive to your needs as a participant? For example, was the agenda flexible or customizable to accommodate your (and others') varying interests or needs? Or was the agenda fixed and followed rigidly?
❍ Almost completely fixed (1)
❍ (2)
❍ Equal mix of fixed and responsive (3)
❍ (4)
❍ Almost completely responsive (5)

10. Was student work or materials a focus of the AP Summer Institute? For example, did you examine student lab reports or student test results as a means to understanding common student errors?
❍ Almost no focus on student work (1)
❍ (2)
❍ Some focus on student work (3)
❍ (4)
❍ Major focus on student work (5)

11. Was teaching modeled as part of the AP Summer Institute? Modeling teaching could include observing demonstrations of the type of teaching that would be seen in AP classes or watching videos from AP classes.
❍ Almost no focus on modeling teaching (1)
❍ (2)
❍ Some focus on modeling teaching (3)
❍ (4)
❍ Major focus on modeling teaching (5)

12. To what extent was the AP Summer Institute intentionally designed to provide opportunities to build collegial and/or supportive relationships with other teachers?
❍ Almost no opportunities to build relationships (1)
❍ (2)
❍ Some opportunities to build relationships (3)
❍ (4)
❍ Ample opportunities to build relationships (5)

13. Did the AP Summer Institute effectively support your needs with respect to teaching the revised AP course?
❍ Not effective (1)
❍ (2)
❍ Somewhat effective (3)
❍ (4)
❍ Extremely effective (5)

14. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Provider had a strong reputation (1)
______ I had the opportunity to interact with other teachers (2)
______ It cost me little or no money (30)
______ It was convenient (29)
______ It emphasized content for the redesigned course (28)
______ It emphasized the redesigned labs (21)
______ It emphasized guidance on structure and planning for the redesigned course (27)
______ It emphasized pedagogy for the redesigned course (26)
______ It was required (7)
______ Other (please describe) (8)

The following questions refer to the **AP Biology 1-day Workshop** provided by the College Board as PD for your AP Science course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with the AP Biology 1-day Workshop PD activity.

15. To what extent did the AP Biology 1-day Workshop include passive and/or active learning experiences? Active learning might include hands-on activities or small-group activities. More passive forms of PD might consist of lectures or presentations.
- ❍ Almost all passive learning (1)
- ❍ (2)
- ❍ Equal mix of passive and active learning (3)
- ❍ (4)
- ❍ Almost all active learning (5)

16. Was the AP Biology 1-day Workshop responsive to your needs as a participant? For example, was the agenda flexible or customizable to accommodate your (and others') varying interests or needs? Or was the agenda fixed and followed rigidly?
- ❍ Almost completely fixed (1)
- ❍ (2)
- ❍ Equal mix of fixed and responsive (3)
- ❍ (4)
- ❍ Almost completely responsive (5)

17. Was student work or materials a focus of the AP Biology 1-day Workshop? For example, did you examine student lab reports or student test results as a means to understanding common student errors?
- ❍ Almost no focus on student work (1)
- ❍ (2)
- ❍ Some focus on student work (3)
- ❍ (4)
- ❍ Major focus on student work (5)

18. Was teaching modeled as part of the AP Biology 1-day Workshop? Modeling teaching could include observing demonstrations of the type of teaching that would be seen in AP classes or watching videos from AP classes.
- ❍ Almost no focus on modeling teaching (1)
- ❍ (2)
- ❍ Some focus on modeling teaching (3)
- ❍ (4)
- ❍ Major focus on modeling teaching (5)

19. To what extent was the AP Biology 1-day Workshop intentionally designed to provide opportunities to build collegial and/or supportive relationships with other teachers?

- ❍ Almost no opportunities to build relationships (1)
- ❍ (2)
- ❍ Some opportunities to build relationships (3)
- ❍ (4)
- ❍ Ample opportunities to build relationships (5)

20. Did the AP Biology 1-day Workshop effectively support your needs with respect to teaching the revised AP course?

- ❍ Not effective (1)
- ❍ (2)
- ❍ Somewhat effective (3)
- ❍ (4)
- ❍ Extremely effective (5)

21. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Provider had a strong reputation (1)
______ I had the opportunity to interact with other teachers (2)
______ It cost me little or no money (26)
______ It was convenient (27)
______ It emphasized content for the redesigned course (28)
______ It emphasized the redesigned labs (21)
______ It emphasized guidance on structure and planning for the redesigned course (29)
______ It emphasized pedagogy for the redesigned course (30)
______ It was required (7)
______ Other (please describe) (8)

The following questions refer to the **Transitioning to Inquiry-Based Labs face-to-face workshop PD** provided by the College Board to support your AP Science course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with the Transitioning to Inquiry-Based Labs face-to-face PD activity.

22. To what extent did the Transitioning to Inquiry-Based Labs PD activity include passive and/or active learning experiences? Active learning might include hands-on activities or small-group activities. More passive forms of PD might consist of lectures or presentations.
❍ Almost all passive learning (1)
❍ (2)
❍ Equal mix of passive and active learning (3)
❍ (4)
❍ Almost all active learning (5)

23. Was the Transitioning to Inquiry-Based Labs PD responsive to your needs as a participant? For example, was the agenda flexible or customizable to accommodate your (and others') varying interests or needs? Or was the agenda fixed and followed rigidly?
❍ Almost completely fixed (1)
❍ (2)
❍ Equal mix of fixed and responsive (3)
❍ (4)
❍ Almost completely responsive (5)

24. Was student work or materials a focus of the Transitioning to Inquiry-Based Labs? For example, did you examine student lab reports or student test results as a means to understanding common student errors?
❍ Almost no focus on student work (1)
❍ (2)
❍ Some focus on student work (3)
❍ (4)
❍ Major focus on student work (5)

25. Was teaching modeled as part of the Transitioning to Inquiry-Based Lab PD? Modeling teaching could include observing demonstrations of the type of teaching that would be seen in AP classes or watching videos from AP classes.
❍ Almost no focus on modeling teaching (1)
❍ (2)
❍ Some focus on modeling teaching (3)
❍ (4)
❍ Major focus on modeling teaching (5)

26. To what extent was the Transitioning to Inquiry-Based Labs PD intentionally designed to provide opportunities to build collegial and/or supportive relationships with other teachers?
❍ Almost no opportunities to build relationships (1)
❍ (2)
❍ Some opportunities to build relationships (3)
❍ (4)
❍ Ample opportunities to build relationships (5)

27. Did the Transitioning to Inquiry-Based Labs PD effectively support your needs with respect to teaching the revised AP course?
❍ Not effective (1)
❍ (2)
❍ Somewhat effective (3)
❍ (4)
❍ Extremely effective (5)

28. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Provider had a strong reputation (1)
______ I had the opportunity to interact with other teachers (2)
______ It cost me little or no money (14)
______ It was convenient (29)
______ It emphasized content for the redesigned course (28)
______ It emphasized the redesigned labs (21)
______ It emphasized guidance on structure and planning for the redesigned course (27)
______ It emphasized pedagogy for the redesigned course (26)
______ It was required (7)
______ Other (please describe) (8)

The following questions refer to the **Day with an AP Reader face-to-face PD** provided by the College Board to support your AP Science course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with the Day with an AP Reader PD activity.

29. To what extent did the Day with an AP Reader PD activity include passive and/or active learning experiences? Active learning might include hands-on activities or small-group activities. More passive forms of PD might consist of lectures or presentations.
- ❍ Almost all passive learning (1)
- ❍ (2)
- ❍ Equal mix of passive and active learning (3)
- ❍ (4)
- ❍ Almost all active learning (5)

30. Was the Day with an AP Reader PD responsive to your needs as a participant? For example, was the agenda flexible or customizable to accommodate your (and others') varying interests or needs? Or was the agenda fixed and followed rigidly?
- ❍ Almost completely fixed (1)
- ❍ (2)
- ❍ Equal mix of fixed and responsive (3)
- ❍ (4)
- ❍ Almost completely responsive (5)

31. Was student work or materials a focus of the Day with an AP Reader PD? For example, did you examine student lab reports or student test results as a means to understanding common student errors?
- ❍ Almost no focus on student work (1)
- ❍ (2)
- ❍ Some focus on student work (3)
- ❍ (4)
- ❍ Major focus on student work (5)

32. Was teaching modeled as part of the Day with an AP Reader PD? Modeling teaching could include observing demonstrations of the type of teaching that would be seen in AP classes or watching videos from AP classes.
- ❍ Almost no focus on modeling teaching (1)
- ❍ (2)
- ❍ Some focus on modeling teaching (3)
- ❍ (4)
- ❍ Major focus on modeling teaching (5)

33. To what extent was the Day with an AP Reader PD intentionally designed to provide opportunities to build collegial and/or supportive relationships with other teachers?
- ❍ Almost no opportunities to build relationships (1)
- ❍ (2)
- ❍ Some opportunities to build relationships (3)
- ❍ (4)
- ❍ Ample opportunities to build relationships (5)

34. Did the Day with an AP Reader PD effectively support your needs with respect to teaching the revised AP course?
- ❍ Not effective (1)
- ❍ (2)
- ❍ Somewhat effective (3)
- ❍ (4)
- ❍ Extremely effective (5)

35. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Provider had a strong reputation (1)
______ I had the opportunity to interact with other teachers (2)
______ It cost me little or no money (14)
______ It was convenient (29)
______ It emphasized content for the redesigned course (28)
______ It emphasized the redesigned labs (21)
______ It emphasized guidance on structure and planning for the redesigned course (27)
______ It emphasized pedagogy for the redesigned course (26)
______ It was required (7)
______ Other (please describe) (8)

The following questions refer to the **Laying the Foundation face-to-face PD** provided by the National Math and Science Initiative (NMSI) to support your AP Science course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with the Laying the Foundation PD activity.

36. To what extent did Laying the Foundation PD activity include passive and/or active learning experiences? Active learning might include hands-on activities or small-group activities. More passive forms of PD might consist of lectures or presentations.

- ❍ Almost all passive learning (1)
- ❍ (2)
- ❍ Equal mix of passive and active learning (3)
- ❍ (4)
- ❍ Almost all active learning (5)

37. Was the Laying the Foundation PD responsive to your needs as a participant? For example, was the agenda flexible or customizable to accommodate your (and others') varying interests or needs? Or was the agenda fixed and followed rigidly?

- ❍ Almost completely fixed (1)
- ❍ (2)
- ❍ Equal mix of fixed and responsive (3)
- ❍ (4)
- ❍ Almost completely responsive (5)

38. Was student work or materials a focus of the Laying the Foundation PD? For example, did you examine student lab reports or student test results as a means to understanding common student errors?

- ❍ Almost no focus on student work (1)
- ❍ (2)
- ❍ Some focus on student work (3)
- ❍ (4)
- ❍ Major focus on student work (5)

39. Was teaching modeled as part of the Laying the Foundation PD? Modeling teaching could include observing demonstrations of the type of teaching that would be seen in AP classes or watching videos from AP classes.

- ❍ Almost no focus on modeling teaching (1)
- ❍ (2)
- ❍ Some focus on modeling teaching (3)
- ❍ (4)
- ❍ Major focus on modeling teaching (5)

40. To what extent was the Laying the Foundation PD intentionally designed to provide opportunities to build collegial and/or supportive relationships with other teachers?
- ❍ Almost no opportunities to build relationships (1)
- ❍ (2)
- ❍ Some opportunities to build relationships (3)
- ❍ (4)
- ❍ Ample opportunities to build relationships (5)

41. Did the Laying the Foundation PD effectively support your needs with respect to teaching the revised AP course?
- ❍ Not effective (1)
- ❍ (2)
- ❍ Somewhat effective (3)
- ❍ (4)
- ❍ Extremely effective (5)

42. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Provider had a strong reputation (1)
______ I had the opportunity to interact with other teachers (2)
______ It cost me little or no money (14)
______ It was convenient (29)
______ It emphasized content for the redesigned course (28)
______ It emphasized the redesigned labs (21)
______ It emphasized guidance on structure and planning for the redesigned course (27)
______ It emphasized pedagogy for the redesigned course (26)
______ It was required (7)
______ Other (please describe) (8)

The following questions refer to the **BSCS Leadership Academy face-to-face PD** provided by BSCS and NABT to support your AP Science course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with the BSCS Leadership Academy PD activity.

43. To what extent did BSCS Leadership Academy PD activity include passive and/or active learning experiences? Active learning might include hands-on activities or small-group activities. More passive forms of PD might consist of lectures or presentations.
❍ Almost all passive learning (1)
❍ (2)
❍ Equal mix of passive and active learning (3)
❍ (4)
❍ Almost all active learning (5)

44. Was the BSCS Leadership Academy PD responsive to your needs as a participant? For example, was the agenda flexible or customizable to accommodate your (and others') varying interests or needs? Or was the agenda fixed and followed rigidly?
❍ Almost completely fixed (1)
❍ (2)
❍ Equal mix of fixed and responsive (3)
❍ (4)
❍ Almost completely responsive (5)

45. Was student work or materials a focus of the BSCS Leadership Academy PD? For example, did you examine student lab reports or student test results as a means to understanding common student errors?
❍ Almost no focus on student work (1)
❍ (2)
❍ Some focus on student work (3)
❍ (4)
❍ Major focus on student work (5)

46. Was teaching modeled as part of the BSCS Leadership Academy PD? Modeling teaching could include observing demonstrations of the type of teaching that would be seen in AP classes or watching videos from AP classes.
❍ Almost no focus on modeling teaching (1)
❍ (2)
❍ Some focus on modeling teaching (3)
❍ (4)
❍ Major focus on modeling teaching (5)

47. To what extent was the BSCS Leadership Academy PD intentionally designed to provide opportunities to build collegial and/or supportive relationships with other teachers?
- ❍ Almost no opportunities to build relationships (1)
- ❍ (2)
- ❍ Some opportunities to build relationships (3)
- ❍ (4)
- ❍ Ample opportunities to build relationships (5)

48. Did the BSCS Leadership Academy PD effectively support your needs with respect to teaching the revised AP course?
- ❍ Not effective (1)
- ❍ (2)
- ❍ Somewhat effective (3)
- ❍ (4)
- ❍ Extremely effective (5)

49. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Provider had a strong reputation (1)
______ I had the opportunity to interact with other teachers (2)
______ It cost me little or no money (14)
______ It was convenient (29)
______ It emphasized content for the redesigned course (28)
______ It emphasized the redesigned labs (21)
______ It emphasized guidance on structure and planning for the redesigned course (27)
______ It emphasized pedagogy for the redesigned course (26)
______ It was required (7)
______ Other (please describe) (8)

The following questions refer to your experience with **district, regional, local college, or teacher-initiated meetings as PD** for your AP Course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with district, regional, local college, or teacher-initiated meetings as a PD activity.

50. To what extent did these PD meetings include passive and/or active learning experiences? Active learning might include hands-on activities or small-group activities. More passive forms of PD might consist of lectures or presentations.
- ❍ Almost all passive learning (1)
- ❍ (2)
- ❍ Equal mix of passive and active learning (3)
- ❍ (4)
- ❍ Almost all active learning (5)

51. Were these PD meetings responsive to your needs as a participant? For example, was the agenda flexible or customizable to accommodate your (and others') varying interests or needs? Or was the agenda fixed and followed rigidly?
- ❍ Almost completely fixed (1)
- ❍ (2)
- ❍ Equal mix of fixed and responsive (3)
- ❍ (4)
- ❍ Almost completely responsive (5)

52. Was student work or materials a focus of district, regional, local college, or teacher-initiated meetings? For example, did you examine student lab reports or student test results as a means to understanding common student errors?
- ❍ Almost no focus on student work (1)
- ❍ (2)
- ❍ Some focus on student work (3)
- ❍ (4)
- ❍ Major focus on student work (5)

53. Was teaching modeled as part of these PD meetings? Modeling teaching could include observing demonstrations of the type of teaching that would be seen in AP classes or watching videos from AP classes.
- ❍ Almost no focus on modeling teaching (1)
- ❍ (2)
- ❍ Some focus on modeling teaching (3)
- ❍ (4)
- ❍ Major focus on modeling teaching (5)

54. To what extent were these PD meeting intentionally designed to provide opportunities to build collegial and/or supportive relationships with other teachers?
- ❍ Almost no opportunities to build relationships (1)
- ❍ (2)
- ❍ Some opportunities to build relationships (3)
- ❍ (4)
- ❍ Ample opportunities to build relationships (5)

55. Did these PD meetings effectively support your needs with respect to teaching the revised AP course?
- ❍ Not effective (1)
- ❍ (2)
- ❍ Somewhat effective (3)
- ❍ (4)
- ❍ Extremely effective (5)

56. Were the PD meetings conducted all at one time (e.g., in a single day or over a week in the summer), or spread out over the academic year (e.g., monthly gatherings)?
- ❍ All within one day (i.e., 8 hours or fewer all in one "sitting") (1)
- ❍ All within one week (i.e., up to 40 hours over 5-7 days) (2)
- ❍ Spread out over a month (3)
- ❍ Spread out across an entire semester (4)
- ❍ Spread out across the entire school year (5)

57. Roughly how many teachers were -- on average or typically -- involved in these PD meetings?
- ❍ 2-5 (1)
- ❍ 6-10 (2)
- ❍ 11-15 (3)
- ❍ 16-20 (4)
- ❍ 21-25 (5)
- ❍ 26-30 (6)
- ❍ 31-35 (7)
- ❍ 36-40 (8)
- ❍ 41-45 (9)
- ❍ 46-50 (10)
- ❍ More than 50 (11)

58. Approximately how long (in hours) were these PD meetings as a whole? (If there were multiple sessions, we are interested in the total duration.

59. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Provider had a strong reputation (14)
______ I had the opportunity to interact with other teachers (2)
______ It cost me little or no money (15)
______ It was convenient (27)
______ It emphasized content for the redesigned course (28)
______ It emphasized the redesigned labs (22)
______ It emphasized guidance on structure and planning for the redesigned course (29)
______ It emphasized pedagogy for the redesigned course (30)
______ It was required (7)
______ Other (please describe) (8)

The following questions refer to your experiences with **Mentoring or Coaching as PD** for your AP Course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with mentoring or coaching as a PD activity.

60. To what extent did your mentoring or coaching include passive and/or active learning experiences? Active learning might include hands-on activities or small-group activities. More passive forms of PD might consist of lectures or presentations.
- ❍ Almost all passive learning (1)
- ❍ (2)
- ❍ Equal mix of passive and active learning (3)
- ❍ (4)
- ❍ Almost all active learning (5)

61. Was the mentoring or coaching responsive to your needs as a participant? For example, was the agenda flexible or customizable to accommodate your (and others') varying interests or needs? Or was the agenda fixed and followed rigidly?
- ❍ Almost completely fixed (1)
- ❍ (2)
- ❍ Equal mix of fixed and responsive (3)
- ❍ (4)
- ❍ Almost completely responsive (5)

62. Was student work or materials a focus of mentoring or coaching? For example, did you examine student lab reports or student test results as a means to understanding common student errors?
- ❍ Almost no focus on student work (1)
- ❍ (2)
- ❍ Some focus on student work (3)
- ❍ (4)
- ❍ Major focus on student work (5)

63. Was teaching modeled as part of the mentoring or coaching? Modeling teaching could include observing demonstrations of the type of teaching that would be seen in AP classes or watching videos from AP classes.
- ❍ Almost no focus on modeling teaching (1)
- ❍ (2)
- ❍ Some focus on modeling teaching (3)
- ❍ (4)
- ❍ Major focus on modeling teaching (5)

64. To what extent was the mentoring or coaching intentionally designed to provide opportunities to build collegial and/or supportive relationships with other teachers?
- Almost no opportunities to build relationships (1)
- (2)
- Some opportunities to build relationships (3)
- (4)
- Ample opportunities to build relationships (5)

65. Did the mentoring or coaching effectively support your needs with respect to teaching the revised AP course?
- Not effective (1)
- (2)
- Somewhat effective (3)
- (4)
- Extremely effective (5)

66. Was the mentoring or coaching conducted all at one time (e.g., in a single day or over a week in the summer), or spread out over the academic year (e.g., monthly gatherings)?
- All within one day (i.e., 8 hours or fewer all in one "sitting") (1)
- All within one week (i.e., up to 40 hours over 5-7 days) (2)
- Spread out over a month (3)
- Spread out across an entire semester (4)
- Spread out across the entire school year (5)

67. Roughly how many teachers were involved in the mentoring or coaching activities with you?
- 2-5 (1)
- 6-10 (2)
- 11-15 (3)
- 16-20 (4)
- 21-25 (5)
- 26-30 (6)
- 31-35 (7)
- 36-40 (8)
- 41-45 (9)
- 46-50 (10)
- More than 50 (11)

68. Approximately how long (in hours) was spent on mentoring or coaching as a whole? (If there were multiple sessions, we are interested in the total duration.)

69. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ It had a strong reputation (1)
______ I had the opportunity to interact with other teachers (2)
______ It cost me little or no money (15)
______ It was convenient (27)
______ It emphasized content for the redesigned course (26)
______ It emphasized the redesigned labs (19)
______ It emphasized guidance on structure and planning for the redesigned course (25)
______ It emphasized pedagogy for the redesigned course (24)
______ It was required (7)
______ Other (please describe) (8)

The following questions refer to your experiences with **Conferences or Conference Sessions as a PD activity** for your AP Science course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with conferences or conference sessions as a PD activity.

70. Did participating in conferences or conference sessions effectively support your needs with respect to teaching the revised AP course?
- ❍ Not effective (1)
- ❍ (2)
- ❍ Somewhat effective (3)
- ❍ (4)
- ❍ Extremely effective (5)

71. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Provider had a strong reputation (1)
______ I had the opportunity to interact with other teachers (2)
______ It cost me little or no money (16)
______ It was convenient (25)
______ It emphasized content for the redesigned course (26)
______ It emphasized the redesigned labs (20)
______ It emphasized guidance on structure and planning for the redesigned course (27)
______ It emphasized pedagogy for the redesigned course (28)
______ It was required (7)
______ Other (please describe) (8)

The following questions refer to your experiences as **an AP Exam Reader as a PD activity** for your AP Science course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience as an AP Exam Reader as a PD activity.

72. Did participating as an AP Exam Reader effectively support your needs with respect to teaching the revised AP course?
- ❍ Not effective (1)
- ❍ (2)
- ❍ Somewhat effective (3)
- ❍ (4)
- ❍ Extremely effective (5)

73. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Provider had a strong reputation (1)
______ I had the opportunity to interact with other teachers (2)
______ It cost me little or no money (16)
______ It was convenient (25)
______ It emphasized content for the redesigned course (26)
______ It emphasized the redesigned labs (20)
______ It emphasized guidance on structure and planning for the redesigned course (27)
______ It emphasized pedagogy for the redesigned course (28)
______ It was required (7)
______ Other (please describe) (8)

The following questions refer to your experiences as an **AP Exam Consultant as a PD activity** for your AP Science course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience as an AP Consultant as a PD activity.

74. Did participating as an AP Exam Reader effectively support your needs with respect to teaching the revised AP course?
- ❍ Not effective (1)
- ❍ (2)
- ❍ Somewhat effective (3)
- ❍ (4)
- ❍ Extremely effective (5)

75. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Provider had a strong reputation (1)
______ I had the opportunity to interact with other teachers (2)
______ It cost me little or no money (16)
______ It was convenient (25)
______ It emphasized content for the redesigned course (26)
______ It emphasized the redesigned labs (20)
______ It emphasized guidance on structure and planning for the redesigned course (27)
______ It emphasized pedagogy for the redesigned course (28)
______ It was required (7)
______ Other (please describe) (8)

The following questions refer to the **Transitioning to Inquiry-Based Labs online PD activity** (6 hours), provided by the College Board as support for your AP Science course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with the Transitioning to Inquiry-Based Labs online PD activity.

76. Was student work or materials a focus of the Transitioning to Inquiry-Based Labs online PD? For example, did you examine student lab reports or student test results as a means to understanding common student errors?
❍ Almost no focus on student work (1)
❍ (2)
❍ Some focus on student work (3)
❍ (4)
❍ Major focus on student work (5)

77. Was teaching modeled as part of the Transitioning to Inquiry-Based Labs online PD activity? Modeling teaching could include observing demonstrations of the type of teaching that would be seen in AP classes or watching videos from AP classes.
❍ Almost no focus on modeling teaching (1)
❍ (2)
❍ Some focus on modeling teaching (3)
❍ (4)
❍ Major focus on modeling teaching (5)

78. Did the Transitioning to Inquiry-Based Labs online PD activity effectively support your needs with respect to teaching the revised AP course?
❍ Not effective (1)
❍ (2)
❍ Somewhat effective (3)
❍ (4)
❍ Extremely effective (5)

79. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Provider had a strong reputation (1)
______ I had the opportunity to interact with other teachers (2)
______ It cost me little or no money (14)
______ It was convenient (29)
______ It emphasized content for the redesigned course (28)
______ It emphasized the redesigned labs (21)
______ It emphasized guidance on structure and planning for the redesigned course (27)
______ It emphasized pedagogy for the redesigned course (26)
______ It was required (7)
______ Other (please describe) (8)

The following questions refer to the **Introduction to AP Biology online PD activity** (6 hours) provided by the College Board to support your AP Science course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with the Introduction to AP Biology online PD activity.

80. Was student work or materials a focus of the Introduction to AP Biology online PD? For example, did you examine student lab reports or student test results as a means to understanding common student errors?
- ❍ Almost no focus on student work (1)
- ❍ (2)
- ❍ Some focus on student work (3)
- ❍ (4)
- ❍ Major focus on student work (5)

81. Was teaching modeled as part of the Intro to AP Biology online PD activity? Modeling teaching could include observing demonstrations of the type of teaching that would be seen in AP classes or watching videos from AP classes.
- ❍ Almost no focus on modeling teaching (1)
- ❍ (2)
- ❍ Some focus on modeling teaching (3)
- ❍ (4)
- ❍ Major focus on modeling teaching (5)

82. Did the Intro to AP Biology online PD activity effectively support your needs with respect to teaching the revised AP course?
- ❍ Not effective (1)
- ❍ (2)
- ❍ Somewhat effective (3)
- ❍ (4)
- ❍ Extremely effective (5)

83. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Provider had a strong reputation (14)
______ I had the opportunity to interact with other teachers (2)
______ It cost me little or no money (15)
______ It was convenient (27)
______ It emphasized content for the redesigned course (28)
______ It emphasized the redesigned labs (22)
______ It emphasized guidance on structure and planning for the redesigned course (29)
______ It emphasized pedagogy for the redesigned course (30)
______ It was required (7)
______ Other (please describe) (8)

The following questions refer to the **AP Insight online activity** provided by the College Board as PD for your AP Science course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with the AP Insight online PD activity.

84. To what extent did the AP Insight online PD activity include passive and/or active learning experiences? Active learning might include hands-on activities or small-group activities. More passive forms of PD might consist of lectures or presentations.

- ❍ Almost all passive learning (1)
- ❍ (2)
- ❍ Equal mix of passive and active learning (3)
- ❍ (4)
- ❍ Almost all active learning (5)

85. Was student work or materials a focus of the AP Insight online PD activity? For example, did you examine student lab reports or student test results as a means to understanding common student errors?

- ❍ Almost no focus on student work (1)
- ❍ (2)
- ❍ Some focus on student work (3)
- ❍ (4)
- ❍ Major focus on student work (5)

86. Was teaching modeled as part of the AP Insight online PD activity? Modeling teaching could include observing demonstrations of the type of teaching that would be seen in AP classes or watching videos from AP classes.

- ❍ Almost no focus on modeling teaching (1)
- ❍ (2)
- ❍ Some focus on modeling teaching (3)
- ❍ (4)
- ❍ Major focus on modeling teaching (5)

87. To what extent was the AP Insight online PD activity intentionally designed to provide opportunities to build collegial and/or supportive relationships with other teachers?

- ❍ Almost no opportunities to build relationships (1)
- ❍ (2)
- ❍ Some opportunities to build relationships (3)
- ❍ (4)
- ❍ Ample opportunities to build relationships (5)

88. Did the AP Insight online PD activity effectively support your needs with respect to teaching the revised AP course?
❍ Not effective (1)
❍ (2)
❍ Somewhat effective (3)
❍ (4)
❍ Extremely effective (5)

89. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Provider had a strong reputation (1)
______ I had the opportunity to interact with other teachers (2)
______ It cost me little or no money (30)
______ It was convenient (29)
______ It emphasized content for the redesigned course (28)
______ It emphasized the redesigned labs (21)
______ It emphasized guidance on structure and planning for the redesigned course (27)
______ It emphasized pedagogy for the redesigned course (26)
______ It was required (7)
______ Other (please describe) (8)

90. The redesigned AP science curriculum is built around a core set of SCIENCE PRACTICES. Please help us to understand, which if any of these SCIENCE PRACTICES were a focus in this PD activity.

	No focus (1)	Moderate focus (2)	High focus (3)
Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems. (1)	❍	❍	❍
Science Practice 2: The student can use mathematics appropriately. (2)	❍	❍	❍
Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course. (3)	❍	❍	❍
Science Practice 4: The student can plan and implement data collection strategies appropriate to a particular scientific questions. (4)	❍	❍	❍
Science Practice 5: The student can perform data analysis and evaluation of evidence. (5)	❍	❍	❍
Science Practice 6: The student can work with scientific explanations and theories. (6)	❍	❍	❍
Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains. (7)	❍	❍	❍

91. The redesigned AP science curriculum is built around a core set of BIG IDEAS. Please help us to understand, which if any of these BIG IDEAS were a focus in this PD activity.

	No focus (1)	Moderate focus (2)	High focus (3)
Big Idea 1: The process of evolution drives the diversity and unity of life. (1)	❍	❍	❍
Big Idea 2: Biological systems utilize free energy and molecular building blocks to grow, to reproduce, and to maintain dynamic homeostasis. (2)	❍	❍	❍
Big Idea 3: Living systems store, retrieve, transmit, and respond to information essential to life processes. (3)	❍	❍	❍
Big Idea 4: Biological systems interact, and these systems and their interaction possess complex properties. (4)	❍	❍	❍

The following questions refer to the **AP Teacher Community web site**, provided by the College Board to support your AP Science course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with the AP Teacher Community web site as PD.

92. How often do you receive and READ a "digest" email from the AP Teacher Community?
- ❍ Never (1)
- ❍ Rarely (2)
- ❍ Once a month (3)
- ❍ Weekly (4)
- ❍ Daily (5)

93. How often did/do you VISIT the AP Teacher Community web site?
- ❍ Only once every few months (1)
- ❍ About once per month (2)
- ❍ Every other week (twice per month) (3)
- ❍ Once a week (4)
- ❍ Several times a week (5)
- ❍ Almost every day (6)

94. When you visit the AP Teacher Community web site, about how much time do you typically spend in each session?
- ❍ Less than 5 minutes (1)
- ❍ About 5 to 10 minutes (2)
- ❍ 10 to 20 minutes (3)
- ❍ 20 to 40 minutes (4)
- ❍ More than 40 minutes (5)

95. Was the AP Teacher Community responsive to your needs as a participant? For example, was the agenda flexible or customizable to accommodate your (and others') varying interests or needs? Or was the agenda fixed and followed rigidly?
- ❍ Almost completely fixed (1)
- ❍ (2)
- ❍ Equal mix of fixed and responsive (3)
- ❍ (4)
- ❍ Almost completely responsive (5)

96. Was student work or materials a focus of the AP Teacher Community web site? For example, did you examine student lab reports or student test results as a means to understanding common student errors?

- Almost no focus on student work (1)
- (2)
- Some focus on student work (3)
- (4)
- Major focus on student work (5)

97. Was teaching modeled as part of the AP Teacher Community web site? Modeling teaching could include observing demonstrations of the type of teaching that would be seen in AP classes or watching videos from AP classes.

- Almost no focus on modeling teaching (1)
- (2)
- Some focus on modeling teaching (3)
- (4)
- Major focus on modeling teaching (5)

98. To what extent did the AP Teacher Community provide opportunities to build collegial and/or supportive relationships with other teachers?

- Almost no opportunities to build relationships (1)
- (2)
- Some opportunities to build relationships (3)
- (4)
- Ample opportunities to build relationships (5)

99. Did the AP Teacher Community effectively support your needs with respect to teaching the revised AP course?

- Not effective (1)
- (2)
- Somewhat effective (3)
- (4)
- Extremely effective (5)

100. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ For advice, suggestions, and support (1)
______ I had the opportunity to interact with other teachers (2)
______ It cost me no money (3)
______ It was convenient (4)
______ It emphasized content for the redesigned course (28)
______ It emphasized the redesigned labs (23)
______ It emphasized guidance on structure and planning for the redesigned course (29)
______ It emphasized pedagogy for the redesigned course (30)
______ It was required (19)
______ Other (please describe) (8)

101. What do you typically do when you visit the AP Teacher Community web site? Please click each element on the grid below somewhere between 0 and 100 to indicate the percentage of time you typically spend on different types of activities when visiting the AP Teacher Community. You can slide the ribbon bars after clicking. If you did not engage in a particular activity or do not typically engage in that activity, you can leave the ribbon/bar at "0". NOTE: All activities must total to 100% before you can move on from this item! The total will display automatically for you on the right, and the grid will not let you exceed 100% as you work with different ribbons.

______ Post a new thread (1)
______ Comment on other posts (15)
______ Read other posts and comments (16)
______ Post resources (17)
______ Find resources (18)
______ Other 1 (Please describe) (19)
______ Other 2 (Please describe) (20)

102. Why do you visit the AP Teacher Community (please check all that apply)?
- ❑ To access resources anywhere, anytime about the AP redesign (1)
- ❑ To ask professional questions of peers in a safe environment and receive answers from colleagues (2)
- ❑ To read what other teachers are thinking about and recommending in responding to the AP redesign (3)
- ❑ To share my own ideas and insights (4)
- ❑ For social interactions with peers (5)
- ❑ Other (please explain) (6) ____________________

103. What if anything would improve your experience with the AP Teacher Community?

The following questions refer to the **NSTA Online Community web site**, provided by the College Board to support your AP Science course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with the National Science Teachers' Association (NSTA) Online Community web site as PD.

104. How often do you receive and READ a “digest” email from the NSTA Online Community?
❍ Never (1)
❍ Rarely (2)
❍ Once a month (3)
❍ Weekly (4)
❍ Daily (5)

105. How often did/do you VISIT the NSTA Online Community web site?
❍ Only once every few months (1)
❍ About once per month (2)
❍ Every other week (twice per month) (3)
❍ Once a week (4)
❍ Several times a week (5)
❍ Almost every day (6)

106. When you visit the NSTA Online Community web site, about how much time do you typically spend in each session?
❍ Less than 5 minutes (1)
❍ About 5 to 10 minutes (2)
❍ 10 to 20 minutes (3)
❍ 20 to 40 minutes (4)
❍ More than 40 minutes (5)

107. Was the NSTA Online Community responsive to your needs as a participant? For example, was the agenda flexible or customizable to accommodate your (and others') varying interests or needs? Or was the agenda fixed and followed rigidly?
❍ Almost completely fixed (1)
❍ (2)
❍ Equal mix of fixed and responsive (3)
❍ (4)
❍ Almost completely responsive (5)

108. Was student work or materials a focus of the NSTA Online Community web site? For example, did you examine student lab reports or student test results as a means to understanding common student errors?
- ❍ Almost no focus on student work (1)
- ❍ (2)
- ❍ Some focus on student work (3)
- ❍ (4)
- ❍ Major focus on student work (5)

109. Was teaching modeled as part of the NSTA Online Community web site? Modeling teaching could include observing demonstrations of the type of teaching that would be seen in AP classes or watching videos from AP classes.
- ❍ Almost no focus on modeling teaching (1)
- ❍ (2)
- ❍ Some focus on modeling teaching (3)
- ❍ (4)
- ❍ Major focus on modeling teaching (5)

110. To what extent did the NSTA Online Community provide opportunities to build collegial and/or supportive relationships with other teachers?
- ❍ Almost no opportunities to build relationships (1)
- ❍ (2)
- ❍ Some opportunities to build relationships (3)
- ❍ (4)
- ❍ Ample opportunities to build relationships (5)

111. Did the NSTA Online Community effectively support your needs with respect to teaching the revised AP course?
- ❍ Not effective (1)
- ❍ (2)
- ❍ Somewhat effective (3)
- ❍ (4)
- ❍ Extremely effective (5)

112. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ For advice, suggestions, and support (1)
______ I had the opportunity to interact with other teachers (2)
______ It cost me no money (3)
______ It was convenient (4)
______ It emphasized content for the redesigned course (28)
______ It emphasized the redesigned labs (23)
______ It emphasized guidance on structure and planning for the redesigned course (29)
______ It emphasized pedagogy for the redesigned course (30)
______ It was required (19)
______ Other (please describe) (8)

113. What do you typically do when you visit the NSTA Online Community web site? Please click each element on the grid below somewhere between 0 and 100 to indicate the percentage of time you typically spend on different types of activities when visiting the NSTA Online Community. You can slide the ribbon bars after clicking. If you did not engage in a particular activity or do not typically engage in that activity, you can leave the ribbon/bar at "0". NOTE: All activities must total to 100% before you can move on from this item! The total will display automatically for you on the right, and the grid will not let you exceed 100% as you work with different ribbons.
______ Post a new thread (1)
______ Comment on other posts (15)
______ Read other posts and comments (16)
______ Post resources (17)
______ Find resources (18)
______ Other 1 (Please describe) (19)
______ Other 2 (Please describe) (20)

114. Why do you visit the NSTA Online Community (please check all that apply)?
- ❑ To access resources anywhere, anytime about the AP redesign (1)
- ❑ To ask professional questions of peers in a safe environment and receive answers from colleagues (2)
- ❑ To read what other teachers are thinking about and recommending in responding to the AP redesign (3)
- ❑ To share my own ideas and insights (4)
- ❑ For social interactions with peers (5)
- ❑ Other (please explain) (6) ____________________

115. What if anything would improve your experience with the NSTA Online Community?

The following questions refer to the **AP Course and Exam Description** provided by the College Board. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with the College Board provided AP Course and Exam Description as a source of PD support for teaching your AP course.

116. Did the AP Course and Exam Description effectively support your needs with respect to teaching the revised AP course?
- ❍ Not effective (1)
- ❍ (2)
- ❍ Somewhat effective (3)
- ❍ (4)
- ❍ Extremely effective (5)

117. Roughly how often did you consult the AP Course and Exam Description for your course?
- ❍ Daily (1)
- ❍ Weekly (2)
- ❍ Monthly (3)
- ❍ Less than Monthly (4)
- ❍ Only once (5)

118. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Creator had a strong reputation (1)
______ It cost me little or no money (4)
______ It was convenient (19)
______ It emphasized content for the redesigned course (18)
______ It emphasized the redesigned labs (13)
______ It emphasized guidance on structure and planning for the redesigned course (20)
______ It emphasized pedagogy for the redesigned course (21)
______ It was required (22)
______ Other (please describe) (8)

The following questions refer to the **AP Lab Manual** provided by the College Board. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with the College Board provided AP Lab Manual as a source of PD support for teaching your AP course.

119. Did the AP Lab Manual effectively support your needs with respect to teaching the revised AP course?
- ❍ Not effective (1)
- ❍ (2)
- ❍ Somewhat effective (3)
- ❍ (4)
- ❍ Extremely effective (5)

120. Roughly how often did you consult the AP Lab Manual?
- ❍ Daily (1)
- ❍ Weekly (2)
- ❍ Monthly (3)
- ❍ Less than Monthly (4)
- ❍ Only once (5)

121. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Creator had a strong reputation (1)
______ It cost me little or no money (15)
______ It was convenient (31)
______ It emphasized content for the redesigned course (30)
______ It emphasized the redesigned labs (22)
______ It emphasized guidance on structure and planning for the redesigned course (29)
______ It emphasized pedagogy for the redesigned course (28)
______ It was required (27)
______ Other (please describe) (8)

The following questions refer to the **Practice AP Exams** provided by the College Board. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with the Practice AP Exams as a source of PD support for teaching your AP course.

122. Did the Practice AP Exams effectively support your needs with respect to teaching the revised AP course?
- ❍ Not effective (1)
- ❍ (2)
- ❍ Somewhat effective (3)
- ❍ (4)
- ❍ Extremely effective (5)

123. Roughly how often did you consult the Practice AP Exams for your course?
- ❍ Daily (1)
- ❍ Weekly (2)
- ❍ Monthly (3)
- ❍ Less than Monthly (4)
- ❍ Only once (5)

124. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Creator had a strong reputation (1)
______ It cost me little or no money (4)
______ It was convenient (19)
______ It emphasized content for the redesigned course (18)
______ It emphasized the redesigned labs (13)
______ It emphasized guidance on structure and planning for the redesigned course (20)
______ It emphasized pedagogy for the redesigned course (21)
______ It was required (22)
______ Other (please describe) (8)

The following questions refer to your **textbook and/or teacher guide as PD** for teaching your AP Science course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with your textbook teacher guide or related materials as a source of PD support for teaching your AP course.

125. Did your textbook or teacher guide effectively support your needs with respect to teaching the revised AP course?
- Not effective (1)
- (2)
- Somewhat effective (3)
- (4)
- Extremely effective (5)

126. Roughly how often did you consult these materials?
- Daily (1)
- Weekly (2)
- Monthly (3)
- Less than Monthly (4)
- Only once (5)

127. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Creator had a strong reputation (1)
______ It cost me little or no money (4)
______ It was convenient (29)
______ It emphasized content for the redesigned course (30)
______ It emphasized the redesigned labs (24)
______ It emphasized guidance on structure and planning for the redesigned course (31)
______ It emphasized pedagogy for the redesigned course (32)
______ It was required (33)
______ Other (please describe) (8)

The following questions refer to your **use of materials developed by colleagues and shared with you** as a source of PD for your AP Science course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with materials developed by colleagues, such as handouts, pacing guides, labs, tests, or quizzes as a source of PD support for teaching your AP course.

128. Did the materials developed by your colleagues effectively support your needs with respect to teaching the revised AP course?
- ❍ Not effective (1)
- ❍ (2)
- ❍ Somewhat effective (3)
- ❍ (4)
- ❍ Extremely effective (5)

129. Roughly how often did you consult these materials?
- ❍ Daily (1)
- ❍ Weekly (2)
- ❍ Monthly (3)
- ❍ Less than Monthly (4)
- ❍ Only once (5)

130. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Creator had a strong reputation (1)
______ It cost me little or no money (30)
______ It was convenient (29)
______ It emphasized content for the redesigned course (28)
______ It emphasized the redesigned labs (20)
______ It emphasized guidance on structure and planning for the redesigned course (27)
______ It emphasized pedagogy for the redesigned course (26)
______ It was required (25)
______ Other (please describe) (8)

The following questions refer to your **use of magazines or journals as a source of PD** for your AP Science course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with magazines or journals as a source of PD support for teaching your AP course.

131. Did the magazines or journals effectively support your needs with respect to teaching the revised AP course?
- ❍ Not effective (1)
- ❍ (2)
- ❍ Somewhat effective (3)
- ❍ (4)
- ❍ Extremely effective (5)

132. Roughly how often did you consult these materials?
- ❍ Daily (1)
- ❍ Weekly (2)
- ❍ Monthly (3)
- ❍ Less than Monthly (4)
- ❍ Only once (5)

133. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Creator had a strong reputation (1)
______ It cost me little or no money (27)
______ It was convenient (28)
______ It emphasized content for the redesigned course (29)
______ It emphasized the redesigned labs (22)
______ It emphasized guidance on structure and planning for the redesigned course (30)
______ It emphasized pedagogy for the redesigned course (31)
______ It was required (20)
______ Other (please describe) (8)

The following questions refer **to video resources** as a source of PD for your AP Science course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with video resources (such as how-to videos for lab equipment or procedures or video guides to teaching techniques, etc.) as a source of PD support for teaching your AP course.

134. Did the video resources effectively support your needs with respect to teaching the revised AP course?
- ❍ Not effective (1)
- ❍ (2)
- ❍ Somewhat effective (3)
- ❍ (4)
- ❍ Extremely effective (5)

135. Roughly how often did you consult the video resources?
- ❍ Daily (1)
- ❍ Weekly (2)
- ❍ Monthly (3)
- ❍ Less than Monthly (4)
- ❍ Only once (5)

136. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Creator had a strong reputation (14)
______ It cost me little or no money (30)
______ It was convenient (29)
______ It emphasized content for the redesigned course (28)
______ It emphasized the redesigned labs (21)
______ It emphasized guidance on structure and planning for the redesigned course (27)
______ It emphasized pedagogy for the redesigned course (26)
______ It was required (19)
______ Other (please describe) (8)

The following questions refer to **online or computer-based simulations** (such as PhET) as a source of PD for your AP Science course. Please respond to the following questions by selecting the best choice from the offered options. Your answers should reflect your personal experience with online simulations (such as PhET) as a source of PD support for teaching your AP course.

137. Did online simulations effectively support your needs with respect to teaching the revised AP course?

- ❍ Not effective (1)
- ❍ (2)
- ❍ Somewhat effective (3)
- ❍ (4)
- ❍ Extremely effective (5)

138. Roughly how often did you consult online simulations?

- ❍ Daily (1)
- ❍ Weekly (2)
- ❍ Monthly (3)
- ❍ Less than Monthly (4)
- ❍ Only once (5)

139. You could have chosen to participate in this PD program or activity for many different reasons. Please rank your top reasons by dragging the small boxes on the left (max=3) to the big box on the right.

Please drag your top 3 reasons for choosing this PD option from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Creator had a strong reputation (14)
______ It cost me little or no money (30)
______ It was convenient (29)
______ It emphasized content for the redesigned course (28)
______ It emphasized the redesigned labs (21)
______ It emphasized guidance on structure and planning for the redesigned course (27)
______ It emphasized pedagogy for the redesigned course (26)
______ It was required (19)
______ Other (please describe) (8)

The questions on this page ask you to reflect on your preparation with respect to core features of the redesigned AP science curriculum: Big Ideas and Science Practices. These items ask you to think about your preparation in general, and about all of the professional development you participated in during the past year.

140. The redesigned AP Biology curriculum contains four "Big Ideas" Big Idea 1 is: The process of evolution drives the diversity and unity of life....

	Not at all (1)	(2)	Moderately (3)	(5)	Extremely (6)
How confident do you feel in teaching this Big Idea? (1)	❍	❍	❍	❍	❍
How much did this year's professional development help you in teaching this Big Idea? (2)	❍	❍	❍	❍	❍

141. Big Idea 2 is: Biological systems utilize free energy and molecular building blocks to grow, to reproduce, and to maintain dynamic homeostasis.

	Not at all (1)	(2)	Moderately (3)	(4)	Extremely (5)
How confident do you feel in teaching this Big Idea? (1)	❍	❍	❍	❍	❍
How much did this year's professional development help you in teaching this Big Idea? (2)	❍	❍	❍	❍	❍

142. Big Idea 3 is: Living systems store, retrieve, transmit, and respond to information essential to life processes.

	Not at all (1)	(2)	Moderately (3)	(4)	Extremely (5)
How confident do you feel in teaching this Big Idea? (1)	❍	❍	❍	❍	❍
How much did this year's professional development help you in teaching this Big Idea? (2)	❍	❍	❍	❍	❍

143. Big Idea 4 is: Biological systems interact, and these systems and their interaction possess complex properties.

	Not at all (1)	(2)	Moderately (3)	(4)	Extremely (5)
How confident do you feel in teaching this Big Idea? (1)	❍	❍	❍	❍	❍
How much did this year's professional development help you in teaching this Big Idea? (2)	❍	❍	❍	❍	❍

144. The redesigned AP Biology curriculum contains seven "Science Practices" Science Practice 1 is: The student can use representations and models to communicate scientific phenomena and solve scientific problems.

	Not at all (1)	(2)	Moderately (3)	(4)	Extremely (5)
How confident do you feel in teaching this Science Practice? (1)	❍	❍	❍	❍	❍
How much did this year's professional development help you in teaching this Science Practice? (2)	❍	❍	❍	❍	❍

145. Science Practice 2 is: The student can use mathematics appropriately.

	Not at all (1)	(2)	Moderately (3)	(4)	Extremely (5)
How confident do you feel in teaching this Science Practice? (1)	❍	❍	❍	❍	❍
How much did this year's professional development help you in teaching this Science Practice? (2)	❍	❍	❍	❍	❍

146. Science Practice 3 is: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.

	Not at all (1)	(2)	Moderately (3)	(4)	Extremely (5)
How confident do you feel in teaching this Science Practice? (1)	❍	❍	❍	❍	❍
How much did this year's professional development help you in teaching this Science Practice? (2)	❍	❍	❍	❍	❍

147. Science Practice 4 is: The student can plan and implement data collection strategies appropriate to a particular scientific questions.

	Not at all (1)	(2)	Moderately (3)	(4)	Extremely (5)
How confident do you feel in teaching this Science Practice? (1)	❍	❍	❍	❍	❍
How much did this year's professional development help you in teaching this Science Practice? (2)	❍	❍	❍	❍	❍

148. Science Practice 5 is: The student can perform data analysis and evaluation of evidence.

	Not at all (1)	(2)	Moderately (3)	(4)	Extremely (5)
How confident do you feel in teaching this Science Practice? (1)	❍	❍	❍	❍	❍
How much did this year's professional development help you in teaching this Science Practice? (2)	❍	❍	❍	❍	❍

149. Science Practice 6 is: The student can work with scientific explanations and theories.

	Not at all (1)	(2)	Moderately (3)	(4)	Extremely (5)
How confident do you feel in teaching this Science Practice? (1)	❍	❍	❍	❍	❍
How much did this year's professional development help you in teaching this Science Practice? (2)	❍	❍	❍	❍	❍

150. Science Practice 7 is: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.

	Not at all (1)	(2)	Moderately (3)	(4)	Extremely (5)
How confident do you feel in teaching this Science Practice? (1)	❍	❍	❍	❍	❍
How much did this year's professional development help you in teaching this Science Practice? (2)	❍	❍	❍	❍	❍

You have finished the toughest part of the survey. Thank you! Please click "Continue" below to keep going with the survey.

Your Teaching Background

151. Approximately how many years have you taught High School Science (not including this year)?

- ❍ 0 years (This is my first year as a high school science teacher) (0)
- ❍ 1 year (1)
- ❍ 2 years (2)
- ❍ 3 years (3)
- ❍ 4 years (4)
- ❍ 5 years (5)
- ❍ 6 years (6)
- ❍ 7 years (7)
- ❍ 8 years (8)
- ❍ 9 years (9)
- ❍ 10 years (10)
- ❍ 11 years (11)
- ❍ 12 years (12)
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- ❍ 14 years (14)
- ❍ 15 years (15)
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- ❍ 36 years (36)
- ❍ 37 years (37)
- ❍ 38 years (38)
- ❍ 39 years (39)

- ❍ 40 years (40)
- ❍ 41 years (41)
- ❍ 42 years (42)
- ❍ 43 years (43)
- ❍ 44 years (44)
- ❍ 45 years (45)
- ❍ 46 years (46)
- ❍ 47 years (47)
- ❍ 48 years (48)
- ❍ 49 years (49)
- ❍ 50 years (50)
- ❍ More than 50 years (51)

152. Approximately how many years have you taught AP Biology (not including this year)?
- 0 years (This is my first year as a AP Biology teacher) (0)
- 1 year (1)
- 2 years (2)
- 3 years (3)
- 4 years (4)
- 5 years (5)
- 6 years (6)
- 7 years (7)
- 8 years (8)
- 9 years (9)
- 10 years (10)
- 11 years (11)
- 12 years (12)
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- 35 years (35)
- 36 years (36)
- 37 years (37)
- 38 years (38)
- 39 years (39)
- 40 years (40)
- 41 years (41)
- 42 years (42)

- 43 years (43)
- 44 years (44)
- 45 years (45)
- 46 years (46)
- 47 years (47)
- 48 years (48)
- 49 years (49)
- 50 years (50)
- More than 50 years (51)

153. As a science teacher, how important is it to you that you be assigned to teach AP Biology?
(Reminder: Nobody from neither the College Board or your school will have access to your individual responses to this or any other question in this survey.)

- If I could, I would always want to teach this course (1)
- I like teaching this course, but would prefer not to teach it every year (2)
- If possible, I would prefer not to teach this course (3)

154. What is your highest degree completed?

- Associate's Degree (1)
- Bachelor's Degree (2)
- Master's Degree (3)
- Certificate of Advanced Study (4)
- Doctoral Degree (5)

155. For the degrees you have earned, what majors/concentrations were represented? (please check all that apply)

- ❑ Life Sciences (e.g., Biology, Biochemistry, etc.) (1)
- ❑ Other sciences (other than life sciences, e.g., Physics, Chemistry, Geology, etc.) (2)
- ❑ Engineering or Computer Science (3)
- ❑ Mathematics or Statistics (4)
- ❑ Humanities (e.g., English, History, etc.) (5)
- ❑ Primary Education (6)
- ❑ Secondary Education (7)

156. Approximately how many courses in Biology did you take in college and graduate school?

- ❍ 0 courses (0)
- ❍ 1 course (1)
- ❍ 2 courses (2)
- ❍ 3 courses (3)
- ❍ 4 courses (4)
- ❍ 5 courses (5)
- ❍ 6 courses (6)
- ❍ 7 courses (7)
- ❍ 8 courses (8)
- ❍ 9 courses (9)
- ❍ 10 courses (10)
- ❍ 11 courses (11)
- ❍ 12 courses (12)
- ❍ 13 courses (13)
- ❍ 14 courses (14)
- ❍ 15 courses (15)
- ❍ 16 courses (16)
- ❍ 17 courses (17)
- ❍ 18 courses (18)
- ❍ 19 courses (19)
- ❍ 20 courses (20)
- ❍ 21 courses (21)
- ❍ 22 courses (22)
- ❍ 23 courses (23)
- ❍ 24 courses (24)
- ❍ 25 courses (25)
- ❍ 26 courses (26)
- ❍ 27 courses (27)
- ❍ 28 courses (28)
- ❍ 29 courses (29)
- ❍ 30 courses (30)
- ❍ More than 30 courses (31)

You have finished 3 out of 9 sections in this survey. Thank you!

Your AP Science Course

157. The next several questions are about your AP Biology class(es), to help us better understand the context in which you teach. What was the approximate start-date of your AP course this school year?

	Month												Day																														
	January (1)	February (2)	March (3)	April (4)	May (5)	June (6)	July (7)	August (8)	September (9)	October (10)	November (11)	December (12)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	8 (8)	9 (9)	10 (10)	11 (11)	12 (12)	13 (13)	14 (14)	15 (15)	16 (16)	17 (17)	18 (18)	19 (19)	20 (20)	21 (21)	22 (22)	23 (23)	24 (24)	25 (25)	26 (26)	27 (27)	28 (28)	29 (29)	30 (30)	31 (31)
(1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

158. What is the approximate end-date of your AP course this school year?

	Month												Day																														
	January (1)	February (2)	March (3)	April (4)	May (5)	June (6)	July (7)	August (8)	September (9)	October (10)	November (11)	December (12)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	8 (8)	9 (9)	10 (10)	11 (11)	12 (12)	13 (13)	14 (14)	15 (15)	16 (16)	17 (17)	18 (18)	19 (19)	20 (20)	21 (21)	22 (22)	23 (23)	24 (24)	25 (25)	26 (26)	27 (27)	28 (28)	29 (29)	30 (30)	31 (31)
(1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

159. Approximately how many students in total do you teach across all of your AP Biology course sections?

- 1-10 students (1)
- 11-20 students (2)
- 21-30 students (3)
- 31-40 students (4)
- 41-50 students (5)
- 51-60 students (6)
- 61-70 students (7)
- 71-80 students (8)
- 81-90 students (9)
- 91-100 students (10)
- 101-110 students (11)
- 111-120 students (12)
- 121-130 students (13)
- 131-140 students (14)
- 141-150 students (15)
- More than 150 students (16)

160. How many sections of AP Biology do you teach?

- 1 section (1)
- 2 sections (2)
- 3 sections (3)
- 4 sections (4)
- 5 sections (5)
- 6 sections (6)
- 7 sections (7)
- More than 7 sections (8)

161. Roughly how many minutes total per week (on average) does each section of your AP Biology class meet?

- Less than 150 minutes (1)
- 151 minutes to 200 minutes (2)
- 201 minutes to 250 minutes (3)
- 251 minutes to 300 minutes (4)
- 301 minutes to 350 minutes (5)
- 351 minutes to 400 minutes (6)
- 401 minutes to 450 minutes (7)
- 451 minutes to 500 minutes (8)
- More than 500 minutes (9)

162. How many preps do you have each week? (i.e., How many different courses do you teach, including AP science?)
- ❍ 1 prep (1)
- ❍ 2 preps (2)
- ❍ 3 preps (3)
- ❍ 4 preps (4)
- ❍ 5 preps (5)
- ❍ 6 preps (6)
- ❍ 7 preps (7)
- ❍ More than 7 preps (8)

163. Roughly what percentage of your enrolled AP students took the AP Biology exam?
- ❍ 0%-25% (1)
- ❍ 26%-50% (2)
- ❍ 51%-75% (3)
- ❍ 76%-90% (4)
- ❍ 91%-99% (5)
- ❍ 100% of my students took the AP Exam (6)

164. Please identify the top 3 most common reasons (e.g., 1, 2, and 3) why students in your class do not take the AP exam.

Please drag your top 3 reasons why students do not take the AP exam from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Nearly 100% of my students took the AP exam (do not choose or rank other options if you rank this one) (10)
______ Cost of AP exam (1)
______ Not feeling prepared for the exam (2)
______ Not planning on attending college (3)
______ Test-averse or test anxiety (4)
______ Limited time due to too many other activities (5)
______ College credit is not a priority (6)
______ College credit is not accepted (7)
______ Other AP courses are more important (8)
______ Other (9)

165. Please identify the top 3 most common ways (e.g., 1, 2, and 3) that the AP exam fee is paid.

Please drag your top 3 ways the AP exam fee is paid from the choices on the left. After you drag the items, please drag to rank them from most important to least
______ Students/parents pay the fee themselves (1)
______ Students obtain funding from external sources (e.g., grants, PTO, etc.) (2)
______ School/district/county/state pays the entire exam fee for all students (3)
______ School/district/county/state pays a portion of the exam fee for all students (4)
______ School/district/county/state shares the cost with parents based on need or students' score (5)
______ Other (6)

166. What is the primary selection criteria (if any) used for enrollment in your AP science course?
- ❍ Basically any student can take the course (no enrollment criteria OR criteria not enforced) (1)
- ❍ Students must meet academic prerequisites (e.g. GPA, previous courses, course grades, exam scores, grade completed, etc.) (2)
- ❍ Students must have formal recommendation, informal department and/or teacher guidance, or demonstrated strong interest (3)

167. In your AP science course(s), what is the rough distribution of student grades? (Please enter numbers below to add up to 100%)

______ A+, A, or A- (1)
______ B+, B, B- (2)
______ C+, C, or C- (3)
______ D+, D, or D- (4)
______ Not passing (5)

168. Has the redesigned AP science course you teach influenced how you teach in other (non-AP) courses? For instance, have you:- made changes in science content coverage or emphasis?- made changes in science practices used or modeled?- made other general pedagogical changes?
- ❍ No changes at all (1)
- ❍ (2)
- ❍ Some changes, or minor changes (3)
- ❍ (4)
- ❍ Many changes, or really important changes (5)

169. Optional - Can you tell us a bit about how your AP science course has influenced your teaching in other (non-AP) courses?

170. Has the redesigned AP science course you teach influenced the way other science courses in your school are taught (by other teachers)? For instance, these changes may be intended to help better prepare students for future AP courses, and include:- changes in science content coverage or emphasis?- changes in science practices used or modeled?- other general pedagogical changes?

- ❍ No changes at all (1)
- ❍ (2)
- ❍ Some changes, or minor changes (3)
- ❍ (4)
- ❍ Many changes, or really important changes (5)

171. Optional - Can you tell us a bit about how your redesigned AP science course has influenced the way other science courses in your school are taught?

172. In the current school year (2014-15), the AP redesign may have posed challenges to your instruction. Please indicate below how much of a challenge each of the following elements of the AP redesign was for you. (Reminder: Nobody from the College Board will have access to your individual responses to this or any other question in this survey.)

	No challenge at all (1)	(2)	A moderate challenge (3)	(4)	A large challenge (5)
Biology content (1)	❍	❍	❍	❍	❍
New Biology content (26)	❍	❍	❍	❍	❍
The organization of Biology content (2)	❍	❍	❍	❍	❍
Essential Knowledge Statements (27)	❍	❍	❍	❍	❍
Big Ideas (28)	❍	❍	❍	❍	❍
Enduring Understandings (29)	❍	❍	❍	❍	❍
Learning Objectives (30)	❍	❍	❍	❍	❍
Labs (3)	❍	❍	❍	❍	❍
Inquiry Labs (4)	❍	❍	❍	❍	❍
Format of questions/problems/exam (5)	❍	❍	❍	❍	❍
Application of science practices to the content (6)	❍	❍	❍	❍	❍
Development of a new syllabus (7)	❍	❍	❍	❍	❍
Understanding the "boundary statements" (8)	❍	❍	❍	❍	❍
Designing new student assessments (9)	❍	❍	❍	❍	❍
Using the textbook for the Biology AP redesign (10)	❍	❍	❍	❍	❍
Working with a new or different textbook (11)	❍	❍	❍	❍	❍
The pacing of my course (12)	❍	❍	❍	❍	❍
Moving my students to a conceptual understanding of Biology (13)	❍	❍	❍	❍	❍
Quantitative Biology (statistics, mathematics) (43)	❍	❍	❍	❍	❍
Other (please describe): (15)	❍	❍	❍	❍	❍

173. In the current (2014-15) school year, how often did you do each of the following in your AP Biology class?

	Never or only once/year (1)	Once/quarter (2)	Once/month (3)	Once/week (4)	Nearly every day (5)
Refer to the "Big Ideas" of Biology (as defined by the AP Biology course and exam description) (1)	❍	❍	❍	❍	❍
Use a science practice in your class outside of the laboratory (2)	❍	❍	❍	❍	❍
Have students work on laboratory investigations (3)	❍	❍	❍	❍	❍
Have students perform guided inquiry laboratory investigations (10)	❍	❍	❍	❍	❍
Provide guidance on test questions which integrate content and process (e.g., essential knowledge and science practices) (4)	❍	❍	❍	❍	❍
Provide guidance on test questions that are open/free response (5)	❍	❍	❍	❍	❍
Have students report laboratory findings to other students (6)	❍	❍	❍	❍	❍
Reference how enduring understandings relate to the "Big Ideas" of Biology (7)	❍	❍	❍	❍	❍
Refer to the Learning Objectives from the AP Biology curriculum in class (8)	❍	❍	❍	❍	❍
Refer to the Curriculum Framework (9)	❍	❍	❍	❍	❍
Refer to the AP Lab Manual (18)	❍	❍	❍	❍	❍
Practice AP Exams from the College Board (17)	❍	❍	❍	❍	❍

174. Approximately how many lab investigations in total did your students complete in the current (2014-15) school year?

- None (0)
- 1 lab investigation (1)
- 2 lab investigations (2)
- 3 lab investigations (3)
- 4 lab investigations (4)
- 5 lab investigations (5)
- 6 lab investigations (6)
- 7 lab investigations (7)
- 8 lab investigations (8)
- 9 lab investigations (9)
- 10 lab investigations (10)
- 11 lab investigations (11)
- 12 lab investigations (12)
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- 16 lab investigations (16)
- 17 lab investigations (17)
- 18 lab investigations (18)
- 19 lab investigations (19)
- 20 lab investigations (20)
- 21 lab investigations (21)
- 22 lab investigations (22)
- 23 lab investigations (23)
- 24 lab investigations (24)
- 25 lab investigations (25)
- 26 lab investigations (26)
- 27 lab investigations (27)
- 28 lab investigations (28)
- 29 lab investigations (29)
- 30 lab investigations (30)
- More than 30 lab investigations (31)

175. Approximately how many of the completed lab investigations were from the AP Biology Lab Guide in the current (2014-15) school year?

- None (0)
- 1 lab investigation (1)
- 2 lab investigations (2)
- 3 lab investigations (3)
- 4 lab investigations (4)
- 5 lab investigations (5)
- 6 lab investigations (6)
- 7 lab investigations (7)
- 8 lab investigations (8)
- 9 lab investigations (9)
- 10 lab investigations (10)
- 11 lab investigations (11)
- 12 lab investigations (12)
- 13 lab investigations (13)

176. The labs in the AP Biology Lab Guide have a major section having to do with skills development and a final few pages that have to do with using those skills to perform a "student-generated" investigation. Of the labs you did from the guide, in how many did your students conduct a student-generated inquiry investigation in the current (2014-15) school year?

- None (0)
- 1 lab investigation (1)
- 2 lab investigations (2)
- 3 lab investigations (3)
- 4 lab investigations (4)
- 5 lab investigations (5)
- 6 lab investigations (6)
- 7 lab investigations (7)
- 8 lab investigations (8)
- 9 lab investigations (9)
- 10 lab investigations (10)
- 11 lab investigations (11)
- 12 lab investigations (12)
- 13 lab investigations (13)

177. Did you teach AP Biology in the school year PRIOR to this one (2013-2014)?

- Yes (1)
- No (0)

178. In the PRIOR (2013-14) school year, how often did you do each of the following in your AP Biology class?

	Never or only once/year (1)	Once/quarter (2)	Once/month (3)	Once/week (4)	Nearly every day (5)
Refer to the "Big Ideas" of Biology (as defined by the AP Biology course and exam description) (1)	❍	❍	❍	❍	❍
Use a science practice in your class outside of the laboratory (2)	❍	❍	❍	❍	❍
Have students work on laboratory investigations (3)	❍	❍	❍	❍	❍
Have students perform inquiry laboratory investigations (10)	❍	❍	❍	❍	❍
Provide guidance on test questions which integrate content and process (e.g., essential knowledge and science practices) (4)	❍	❍	❍	❍	❍
Provide guidance on test questions that are open/free response (5)	❍	❍	❍	❍	❍
Have students report laboratory findings to other students (6)	❍	❍	❍	❍	❍
Reference how enduring understandings relate to the "Big Ideas" of Biology (7)	❍	❍	❍	❍	❍
Refer to the	❍	❍	❍	❍	❍

Learning Objectives from the AP Biology curriculum in class (8)					
Refer to the Curriculum Framework (9)	❍	❍	❍	❍	❍
Refer to the AP Lab Manual (17)	❍	❍	❍	❍	❍
Practice AP Exams from the College Board (18)	❍	❍	❍	❍	❍

179. Approximately how many lab investigations in total did your students complete in the prior (2013-14) school year?

- ❍ None (0)
- ❍ 1 lab investigation (1)
- ❍ 2 lab investigations (2)
- ❍ 3 lab investigations (3)
- ❍ 4 lab investigations (4)
- ❍ 5 lab investigations (5)
- ❍ 6 lab investigations (6)
- ❍ 7 lab investigations (7)
- ❍ 8 lab investigations (8)
- ❍ 9 lab investigations (9)
- ❍ 10 lab investigations (10)
- ❍ 11 lab investigations (11)
- ❍ 12 lab investigations (12)
- ❍ 13 lab investigations (13)
- ❍ 14 lab investigations (14)
- ❍ 15 lab investigations (15)
- ❍ 16 lab investigations (16)
- ❍ 17 lab investigations (17)
- ❍ 18 lab investigations (18)
- ❍ 19 lab investigations (19)
- ❍ 20 lab investigations (20)
- ❍ 21 lab investigations (21)
- ❍ 22 lab investigations (22)
- ❍ 23 lab investigations (23)
- ❍ 24 lab investigations (24)
- ❍ 25 lab investigations (25)
- ❍ 26 lab investigations (51)
- ❍ 27 lab investigations (52)
- ❍ 28 lab investigations (53)
- ❍ 29 lab investigations (54)
- ❍ 30 lab investigations (55)
- ❍ More than 30 lab investigations (26)

180. Approximately how many of the completed lab investigations were from the AP Biology Lab Guide in the prior (2013-14) school year?

- ❍ None (0)
- ❍ 1 lab investigation (1)
- ❍ 2 lab investigations (2)
- ❍ 3 lab investigations (3)
- ❍ 4 lab investigations (4)
- ❍ 5 lab investigations (5)
- ❍ 6 lab investigations (6)
- ❍ 7 lab investigations (7)
- ❍ 8 lab investigations (8)
- ❍ 9 lab investigations (9)
- ❍ 10 lab investigations (10)
- ❍ 11 lab investigations (11)
- ❍ 12 lab investigations (12)
- ❍ 13 lab investigations (13)
- ❍ 14 lab investigations (14)

181. The labs in the AP Biology Lab Guide have a major section having to do with skills development and a final few pages that have to do with using those skills to perform a "student-generated" investigation.
Of the labs you did from the guide, in how many did your students conduct a student-generated inquiry investigation in the prior (2013-14) school year?

- ❍ None (0)
- ❍ 1 lab investigation (1)
- ❍ 2 lab investigations (2)
- ❍ 3 lab investigations (3)
- ❍ 4 lab investigations (4)
- ❍ 5 lab investigations (5)
- ❍ 6 lab investigations (6)
- ❍ 7 lab investigations (7)
- ❍ 8 lab investigations (8)
- ❍ 9 lab investigations (9)
- ❍ 10 lab investigations (10)
- ❍ 11 lab investigations (11)
- ❍ 12 lab investigations (12)
- ❍ 13 lab investigations (13)

More than halfway done (and the remaining sections are shorter)! Thank you!

General Attitudes Towards Professional Development

182. This next set of questions is about your participation in and attitudes towards PD in general (not about any particular PD activity).

	Not at all important (1)	Mostly unimportant (2)	Neither unimportant nor important (3)	Very important (4)	Extremely important (5)
Overall, how important do you think PD (of any kind) is to your performance as an AP science teacher? (1)	❍	❍	❍	❍	❍
Overall, how important do you think your PD (of any kind) is or will be to your students' performance on the AP exam? (2)	❍	❍	❍	❍	❍

183. Please indicate the extent to which you agree or disagree with each of the following statements:

	Strongly disagree (1)	Disagree (2)	Neither disagree nor agree (3)	Agree (4)	Strongly agree (5)
In general, I find that I can just as easily teach myself the things that I learn through formal PD sessions. (3)	❍	❍	❍	❍	❍
In general, I find that my performance as a teacher is not greatly affected by my participation in PD. (7)	❍	❍	❍	❍	❍
In general, I enjoy participating in face-to-face PD activities. (5)	❍	❍	❍	❍	❍
In general, I enjoy participating in online PD activities. (6)	❍	❍	❍	❍	❍

Do you belong to any of these professional organizations related to science teaching? We are thinking of organizations such as: AAAS, AAPT, ACS, AETS, ASE, ASTE, CESI, NABT NAGT, NARST, NESTA, NMEA, NMLSTA, NSTA, SSMA, a science association in your state.

184. Please indicate how many of these types of organization you belong to: (If you don't belong to any of these organizations please select "I don't belong to any professional science education organizations.")

- I don't belong to any professional science education organizations (0)
- I belong to 1 organization (1)
- I belong to 2 organizations (2)
- I belong to 3 organizations (3)
- I belong to 4 organizations (4)
- I belong to 5 organizations (5)
- I belong to more than 5 organizations (6)

185. How many conferences sponsored by the professional science education organizations listed in the previous question have you attended in the past 3 years? (If you didn't attend any science education conferences in the past 3 years please select "I have not attended a professional science education conference in the past 3 years.")

- I have not attended a professional science education conference in the past 3 years (0)
- I have attended 1 conference in the past 3 years (1)
- I have attended 2 conferences in the past 3 years (2)
- I have attended 3 conferences in the past 3 years (3)
- I have attended 4 conferences in the past 3 years (4)
- I have attended 5 conferences in the past 3 years (5)
- I have attended 6 conferences in the past 3 years (6)
- I have attended 7 conferences in the past 3 years (7)
- I have attended 8 conferences in the past 3 years (8)
- I have attended more than 5 conferences in the past 3 years (9)

186. How many years have you served as an official AP Exam Reader? (If you didn't serve as an official AP Exam Reader please select "None.")
- None (0)
- 1 year (including this year) (1)
- 2 years (2)
- 3 years (3)
- 4 years (4)
- 5 years (5)
- 6 years (6)
- 7 years (7)
- 8 years (8)
- 9 years (9)
- 10 years (10)
- More than 10 years (11)

187. How many years have you served as an official AP Consultant? (If you didn't serve as an official AP Consultant please select "None.")
- None (0)
- 1 year (including this year) (1)
- 2 years (2)
- 3 years (3)
- 4 years (4)
- 5 years (5)
- 6 years (6)
- 7 years (7)
- 8 years (8)
- 9 years (9)
- 10 years (10)
- More than 10 years (11)

Your Levels of Concern (Now)

188. For each of the following statements about the AP redesign, please indicate the degree to which it is a concern for you NOW.

	Not at all concerned (1)	(2)	Somewhat concerned (3)	(4)	Very concerned (5)
Preparation for the demands of the AP Redesign. I am concerned that I am not adequately prepared to teach the AP Redesign, I am concerned that teaching the redesigned AP could reflect poorly on me or could be problematic for me professionally. (1)	❍	❍	❍	❍	❍
Making the best use of the information and resources related to the AP Redesign. I am concerned about my ability (preparation) to use the information and resources well. I am concerned that it might affect my ability to be	❍	❍	❍	❍	❍

efficient, and to organize and manage my course. (2)					
Impact of the AP Redesign on my students and/or colleagues. I am concerned about how the AP Redesign will impact my students and colleagues, and I would like to help them do well with the new course and exam. (3)	❍	❍	❍	❍	❍
Mastery of the AP Redesign. I am concerned about how I can get the most out of what AP Redesign has to offer, so that I can provide a better AP science experience for my students. (4)	❍	❍	❍	❍	❍

189. For each of the following statements about the AP redesign, please indicate the degree to which it is a concern for you NOW.

	Not at all concerned (1)	. (2)	Somewhat concerned (3)	. (4)	Very concerned (5)
Overall, how concerned ARE YOU NOW about your ability to teach the revised AP science curriculum? (1)	❍	❍	❍	❍	❍
Overall, how concerned ARE YOU NOW about your ability to help your students achieve their highest possible scores on the AP exam? (2)	❍	❍	❍	❍	❍

You have finished 6 out of 9 sections in this survey. Thank you!

Your Levels of Concern (One Year Ago)

190. For each of the following statements about the AP redesign, please indicate the degree to which it WAS a concern for you ONE YEAR AGO (i.e., prior to the PD for teaching activities related to AP science in the current school year).

	Not at all concerned (1)	(2)	Somewhat concerned (3)	(4)	Very concerned (5)
Preparation for the demands of the AP Redesign. I was concerned that I was not adequately prepared to teach the AP Redesign, I was concerned that teaching the redesigned AP could reflect poorly on me or could be problematic for me professionally. (1)	❍	❍	❍	❍	❍
Making the best use of the information and resources related to the AP Redesign. I was concerned about my ability (preparation) to use the information and resources well. I was concerned	❍	❍	❍	❍	❍

that it might affect my ability to be efficient, and to organize and manage my course. (2)					
Impact of the AP Redesign on my students and/or colleagues. I was concerned about how the AP Redesign would impact my students and colleagues, and I wanted to help them do well with the new course and exam. (3)	❍	❍	❍	❍	❍
Mastery of the AP Redesign. I was concerned about how I could get the most out of what AP Redesign has to offer, so that I could provide a better AP science experience for my students. (4)	❍	❍	❍	❍	❍

191. For each of the following statements about the AP redesign, please indicate the degree to which it WAS a concern for you ONE YEAR AGO (i.e., prior to the PD or teaching activities related to AP science in the current school year).

	Not at all concerned (1)	. (2)	Somewhat concerned (3)	. (4)	Very concerned (5)
Overall, how concerned WERE YOU ONE YEAR AGO about your ability to teach the revised AP science curriculum? (1)	❍	❍	❍	❍	❍
Overall, how concerned WERE YOU ONE YEAR AGO about your ability to help your students achieve their highest possible scores on the AP exam? (2)	❍	❍	❍	❍	❍

Only a few more questions left. Thanks for your effort!

Your AP Science Instruction and Your School Context

192. We have just a few more questions about your beliefs regarding the nature of AP science instruction, the nature of AP in your school, plus some brief demographic questions.
The following questions are about your STUDENTS' relationship to your AP science course.

	Few or none of my students (1)	Some of my students (2)	Most of my students (3)	All of my students (4)
How many of your AP science students take the course so they can earn college credit and place out of an introductory college science course? (1)	❍	❍	❍	❍
How many of your AP science students take the course to experience an advanced, rigorous course in high school? (2)	❍	❍	❍	❍
For how many of your AP science students is this the first AP course that they have experienced? (3)	❍	❍	❍	❍
How many of your AP science students knew what this course would be like before signing up? (4)	❍	❍	❍	❍
Overall, how many of your AP science students do you think are well-served by the AP Redesign? (5)	❍	❍	❍	❍
How many of your students take AP science because it is weighted more heavily in their GPA calculations? (6)	❍	❍	❍	❍

193. The following questions are about YOUR relationship to the revised AP science exam and teaching the course.

	Strongly disagree (1)	Disagree (2)	Neither disagree nor agree (3)	Agree (4)	Strongly agree (5)
When my students do better than usual on their AP science test, it is often because I exerted a little extra effort. (1)	❍	❍	❍	❍	❍
When the AP science scores of my students improve, it is most often because I found a more effective teaching approach. (2)	❍	❍	❍	❍	❍
The quality of my teaching can overcome the inadequacy of my students' AP science background. (3)	❍	❍	❍	❍	❍
Even when I put more effort in my AP science teaching, it produces little change in some of my students' AP science achievement. (4)	❍	❍	❍	❍	❍

194. When did you find out that you were teaching AP science this year?
❍ More than 1 year prior to this school year (1)
❍ More than 3 months prior to the start of this school year, but less than 1 year (2)
❍ Between 1 and 3 months prior to the start of this school year (3)
❍ Less than 1 month prior to the start of this school year (4)
❍ Less than 2 weeks prior to the start of this school year (5)

195. How much equipment do you have available to perform all the labs you would like to complete?
- ❍ None or little of the equipment (1)
- ❍ Some of the equipment (2)
- ❍ Most of the equipment (3)
- ❍ All the equipment (4)

196. How much expendable (consumable) supplies do you have available to perform all the labs you would like to complete?
- ❍ None or little of the expendable supplies (1)
- ❍ Some of the expendable supplies (2)
- ❍ Most of the expendable supplies (3)
- ❍ All of the expendable supplies (4)

197. Do you have sufficient access to computers or other devices (e.g., tablets) that can connect to the Internet for use in your teaching?
- ❍ No or little access (1)
- ❍ Some of the access (2)
- ❍ Most of the access (3)
- ❍ All the access (4)

Some teachers/schools offer opportunities for students to increase their exposure to AP experiences outside of the classroom. We are interested in student participation in these activities for the 2014-2015 school year.

198. Was a "Summer Bridge" program offered during the summer of 2014 for students who are currently enrolled in your AP science course? (This is a program that would meet for multiple days in the summer prior to students' starting to take the AP exam.)
- ❍ Yes (1)
- ❍ No (0)

199. Do you offer or are your students asked to complete AP Summer Assignments? (Students are asked to complete readings independently during the summer prior to studying for the AP exam.)
- ❍ Yes (1)
- ❍ No (0)

200. These items are about your perceived support from your administrator or principal during the current (2014-15) school year. (Reminder: Nobody from neither the College Board or your school will have access to your individual responses to this or any other question in this survey.)

	Strongly disagree (1)	Disagree (2)	Neither disagree nor agree (3)	Agree (4)	Strongly agree (5)
My principal has a good understanding of how challenging AP science courses are for students (1)	❍	❍	❍	❍	❍
My principal has a good understanding of the challenges of teaching an AP science course (2)	❍	❍	❍	❍	❍
My principal is supportive of teacher participation in PD (3)	❍	❍	❍	❍	❍
I am given a lighter teaching load because I teach an AP science course (4)	❍	❍	❍	❍	❍
In comparison to non-AP teachers, I have fewer out of class responsibilities (e.g., hall duty) (5)	❍	❍	❍	❍	❍
AP science is given additional funding by my administrator exclusively for the course (6)	❍	❍	❍	❍	❍

201. In general, how does your PD get paid for? (Please pick the one option that best describes your situation.)

- My school pays for any PD I choose (1)
- My school pays a fixed amount that I can use towards any PD I choose (2)
- My school only pays for PD that is required (3)
- I make requests for PD support and the school may or may not approve (4)
- My school provides no financial support for PD and I pay out of pocket (5)
- My school provides no financial support and I seek out scholarship funds (6)
- Other (7) ____________________

You have finished 8 out of 9 sections in this survey. Thank you!

A few final demographic questions...

202. What is your gender?
- ❍ Male (1)
- ❍ Female (2)
- ❍ Other (3)

203. Are you of Hispanic or Latino origin?
- ❍ Yes (1)
- ❍ No (0)

204. What is your race (mark all that apply):
- ❑ American Indian or Alaska Native (1)
- ❑ Asian (2)
- ❑ Black or African American (3)
- ❑ Native Hawaiian or other Pacific Islander (4)
- ❑ White (5)

205. What year were you born?

- ❍ 1997 (18)
- ❍ 1996 (19)
- ❍ 1995 (20)
- ❍ 1994 (21)
- ❍ 1993 (22)
- ❍ 1992 (23)
- ❍ 1991 (24)
- ❍ 1990 (25)
- ❍ 1989 (26)
- ❍ 1988 (27)
- ❍ 1987 (28)
- ❍ 1986 (29)
- ❍ 1985 (30)
- ❍ 1984 (31)
- ❍ 1983 (32)
- ❍ 1982 (33)
- ❍ 1981 (34)
- ❍ 1980 (35)
- ❍ 1979 (36)
- ❍ 1978 (37)
- ❍ 1977 (38)
- ❍ 1976 (39)
- ❍ 1975 (40)
- ❍ 1974 (41)
- ❍ 1973 (42)
- ❍ 1972 (43)
- ❍ 1971 (44)
- ❍ 1970 (45)
- ❍ 1969 (46)
- ❍ 1968 (47)
- ❍ 1967 (48)
- ❍ 1966 (49)
- ❍ 1965 (50)
- ❍ 1964 (51)
- ❍ 1963 (52)
- ❍ 1962 (53)
- ❍ 1961 (54)
- ❍ 1960 (55)
- ❍ 1959 (56)
- ❍ 1958 (57)
- ❍ 1957 (58)
- ❍ 1956 (59)
- ❍ 1955 (60)

- ❍ 1954 (61)
- ❍ 1953 (62)
- ❍ 1952 (63)
- ❍ 1951 (64)
- ❍ 1950 (65)
- ❍ 1949 (66)
- ❍ 1948 (67)
- ❍ 1947 (68)
- ❍ 1946 (69)
- ❍ 1945 (70)
- ❍ 1944 (71)
- ❍ 1943 (72)
- ❍ 1942 (73)
- ❍ 1941 (74)
- ❍ 1940 (75)
- ❍ 1939 (76)
- ❍ 1938 (77)
- ❍ 1937 (78)
- ❍ 1936 (79)
- ❍ 1935 (80)
- ❍ 1934 (81)
- ❍ 1933 (82)
- ❍ 1932 (83)
- ❍ 1931 (84)
- ❍ 1930 (85)

Almost there! Just one more page... The last page has more information about our thank you gifts to you.

THANK YOU for participating in this survey and supporting research to help improve future PD for all AP teachers.

Below, we describe how to receive your certificate, describe some of the other rewards available to you, and ask if you would like to opt-in to the drawing for $100. Regardless of your interest in the incentives, please remember to click "Submit Survey" at the bottom of this page.

A Certificate of Appreciation
If you would like an official certificate thanking you for your participation in this survey (for yourself and/or to share with your administrator), please click this link: http://umassboston.net/cosmic/surveyPlease copy or save this link if you wish to print your certificate at a later time.

As an additional thank you, we are pleased to be able to offer you the following:
The opportunity to participate in a live presentation by the Chief Reader about scoring the AP exam. The 1-hour presentation will focus on how the readers graded this year's exams.

All participants will receive a draft of the official free response scoring guidelines for the May 2015 AP Biology exam. These rubrics will be distributed before the official version is published. You will receive an email message from the College Board with more information about this opportunity.

A chance to win $100.
Winners will be selected every day, and if you are not a winner, you will be entered into the next day's drawing.
Note: Although the confidentiality of your survey responses will not be breached, in order to ascertain if you are a winner, we must contact the College Board to connect your unique survey identifier with your email address and name so that the University of Massachusetts Boston can distribute the $100. By entering this lottery, you consent to allowing us to obtain your contact information from the College Board if you are a winner. You also consent to allowing your name to be released as part of a list of all winners should we receive a request for information about who won the drawing. All winners will be notified by email after July 15, 2015.

If you would like to receive a list of drawing winners, please send an email message to ProfDevSurveyGift2@gmail.com. Please copy or save this email address for access after you complete the survey. Once your survey is submitted, you will no longer have access to this page.

Please check the box below to indicate that you wish to be entered in this drawing.
- ☐ YES! Enter me in a drawing for the chance to win $100. (1)

This survey is part of a larger study, with multiple components:
To help us understand AP teachers' PD experiences in greater depth, we will be contacting a small number of teachers to develop in-depth studies of their PD and AP Science teaching.

Please check the box below to indicate your willingness to be considered for one of the in-depth studies:

- ❑ YES! I am willing to be considered for participation in the in-depth study portion of this research. (2)

THANK YOU!
Please click "Submit Survey" to complete the survey and have your answers recorded.