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Sustaining shifts in science teaching through a research–practice partnership

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Abstract

This study examines shifts in science teachers' ($N = 15$) beliefs and practices within the context of a research–practice partnership (RPP) that developed and implemented curriculum modules in middle school science classrooms. Interview, document, and observation data gathered over the course of the project indicate that the vast majority of teachers intended to continue using the curriculum modules in their classrooms for the foreseeable future. These data also documented potential shifts in teacher attitudes and practices inspired by the modules. Among teacher participants, there were clear examples of teachers modifying other lesson plans to resemble key components of the modules, using module implementation as a context for developing proficiency with inquiry-oriented teaching, and revisiting or drawing connections to the modules when teaching other science content. The study also documented the typical sequence of shifts in teachers' beliefs and practices, with findings indicating that teacher beliefs were most powerfully influenced by their observations of student performance and engagement during module implementation. By following teachers' beliefs and practices beyond the official implementation timeline of the project, the study lends insight into the ways in which curriculum resources developed in the context of RPPs may have a lasting impact at the classroom level.

KEYWORDS

curriculum, curriculum development, professional development, research-practice partnership, science/science education, teachers and teaching

1 | INTRODUCTION

The Next Generation Science Standards (NGSS) redefined science teaching and learning in the United States. This redefinition requires fostering and sustaining new understandings and practices among science teachers as they work toward the NGSS vision of three-dimensional (3D) learning experiences that deepen students' understanding of disciplinary core ideas, science and engineering practices, and cross-cutting concepts (Anderson et al., 2018; Berland et al., 2016; Bybee, 2014; National Research Council, 2012; NGSS Lead States, 2013).

Supported by an NSF Math–Science partnership grant, the Advanced Manufacturing and Prototyping Integrated to Unlock Potential (AMP-IT-UP) project established a research–practice partnership (RPP) that iteratively developed week-long science and mathematics modules organized around three NGSS-aligned practices:

experimental design, data visualization, and data-driven decision making. Over the course of a multi-year curriculum development cycle, the RPP introduced math and science curriculum modules at each grade level (6th–8th grade) in the partner district's four middle schools. In addition to providing new curriculum modules as an NGSS-aligned resource, the project envisioned the possibility of influencing teacher attitudes and teaching practices beyond the relatively short module implementation period and, ultimately, beyond the horizon of the formal partnership with the district.

2 | BACKGROUND LITERATURE

Changing teacher practice represents a major theme in the science education literature, with a multitude of studies exploring factors that influence teacher practice including professional development (PD) (Fishman et al., 2003; Guskey, 2002; Lumpe et al., 2012; Miller et al., 2021; Pringle et al., 2018), science education policy and curricular reform efforts (Luft & Hewson, 2014; Penuel et al., 2009; Pruitt, 2014; Shaver et al., 2007; Spillane et al., 2001), teacher beliefs (Luft, 2001; Lumpe et al., 2000; Marco-Bujosa et al., 2021), and assessment (Deboer, 2002; Klassen, 2006). As a thorough review of this body of literature is beyond the scope of this paper, we focus on highlighting key findings from recent work examining changes in science teaching precipitated by NGSS-aligned PD or curriculum projects and RPPs.

Researchers have described changes in teacher practices and beliefs in the context of PD initiatives designed to support NGSS implementation and 3D instruction (Hayes et al., 2017; Lehrer & Schauble, 2012; McNeill & Knight, 2013; Parke & Coble, 1998; Pringle et al., 2018; Southerland et al., 2016). One study by Hayes et al. (2019) examined how participants in a PD institute integrated the NGSS and environmental education using a stewardship approach. The study found that changes in instructional practices stemmed from a shift in teachers' beliefs that stewardship was possible within the accountability-based context in which they taught. Further, the study found that the shift in teachers' beliefs resulted from a combination of factors including resources provided by PD, observations of student engagement, and NGSS justification for stewardship activities. A mixed-methods study by Pringle et al. (2018) examined the effects of a comprehensive PD program on science teachers' content knowledge and instructional practices. Findings of the study indicated significant improvements in teachers' disciplinary content knowledge and variations in teachers' ability to translate knowledge into instructional practices consistent with the PD. Based on these findings, the study concluded that PD programs that exemplify elements of effective PD, as defined by the literature, can have a positive influence on middle school science teachers' enactment of reform-based science teaching. In a similar vein, Blanchard and Sampson (2017) present case study findings illustrating shifts in teachers' conceptions about inquiry and lesson design following participation in a Research Experiences for Teachers (RET) PD program. The study concluded that significant changes in how teachers thought about inquiry and how they designed their lessons stemmed from adoption of inquiry-based approaches modeled during the science pedagogy-focused RET experience.

As the science education community has responded to calls for the "substantial redesign" of curricula in order to provide opportunities for students to develop proficiency with disciplinary core ideas, science and engineering practices, and crosscutting concepts, researchers have examined changes in teacher beliefs and practices driven by design-based curriculum development initiatives (National Research Council, 2012, p. 247). Although there is a rich history of design-based research leading to new and innovative classroom practice (Lehrer & Schauble, 2012; McNeill & Knight, 2013), researchers engaged in this work have noted the challenge of sustaining and scaling instructional programs beyond design-based research contexts, where teachers often have access to resources and support that cannot always be taken to scale (Penuel & Gallagher, 2017). Anderson et al. (2018) take up the question of how classrooms can be supported at scale to achieve 3D learning goals of the NGSS in their study examining outcomes of their Carbon TIME project, which focuses on the teaching of carbon cycling and energy transformation. The study concluded that while it is possible to measure and achieve 3D learning at scale, doing so requires significant investment in material, human, and social resources of educational communities of practice.

Of particular relevance to the current study is research exploring curriculum enactment and adaptation in the context of RPPs (Debarger et al., 2017; Harris et al., 2014; Penuel & Gallagher, 2017). Debarger et al. (2017) investigated science teachers' purposeful adaptations of curriculum and found that when provided supportive guidance from an RPP, teachers purposefully adapted curriculum materials in ways that showed promise for improving student understanding of science. For example, the study found connections between shifts in classroom culture fostered by specific adaptations, such as employing "talk moves" to foster academically productive talk, and advances in student understanding of focal science ideas.

Understanding how new curricula are taken up requires attending to teachers' attitudes and beliefs related to curriculum and, specifically, the ways in which teachers exercise agency when deciding to incorporate and sustain curricular innovations (Century & Cassata, 2016; Penuel & Gallagher, 2017; Severance et al., 2016). Indeed, our experience working with science teachers within the context of this RPP underscores the important role that teachers play as advocates and agents of curricular innovation. To this end, the study draws on data collected over a 2-year period to explore the ways in which teachers' RPP experiences influenced their approach to science teaching. The study addresses the following research question: To what extent and in what ways does participation in the RPP through PD and module implementation influence broader shifts in science teaching beyond the modules?

3 | THEORETICAL FRAMEWORK

Guskey's (2002) Model of Teacher Change (Figure 1) describes the process by which changes in teacher practice may occur and be sustained. Specifically, the model describes the relationship among three areas of change: change in the classroom practices, change in teacher attitudes and beliefs, and student learning outcomes. Critically, this model challenges the assumption that shifting teachers' attitudes and beliefs is prerequisite to changes in classroom practice. Conversely, the model posits a sequence in which significant changes in teachers' attitudes and beliefs typically occur *after* they have made changes in their classroom practice and observed evidence of improved student outcomes. According to Guskey, 2002, “it is not the PD per se, but the experience of successful implementation that changes teachers' attitudes and beliefs. They believe it works because they have seen it work, and that experience shapes their attitudes and beliefs” (p. 383). Thus, Guskey describes student learning outcomes as “the key to the endurance of any change in instructional practice” (p. 384), noting that teachers typically retain aspects of practice that they find useful for achieving certain learning outcomes and abandon practices that do not yield demonstrable results. Importantly, Guskey construes student learning outcomes broadly to include “whatever kinds of evidence teachers use to judge the effectiveness of their teaching” (p. 384), including not only student achievement but also student behavior, attendance, engagement, attitudes, and motivation.

Applied to the current study, this framework provides a lens for examining the degree to which participating in the AMP-IT-UP project facilitated possible shifts in teacher practice, beliefs and attitudes. Examining teachers' perspectives on the curriculum modules provides an opportunity to develop understandings of how changes in classroom practice (module implementation) may have precipitated changes in teacher attitudes and beliefs and whether changes in teacher attitudes and beliefs were mediated by teachers' assessment about whether the modules improved learning outcomes for their students. Because the study takes place within the context of an RPP wherein teachers were encouraged to provide feedback to inform curriculum development, we continually received teachers' assessment of what elements of the modules “worked” for their students and which were less successful. From observations and teachers' reports on their experience, we can explore how these assessments of what worked influenced teachers' attitudes and beliefs and their intentions for sustaining changes in their classroom practice. Although the basic model is presented as a linear progression, Guskey acknowledges the possibility that the process of teacher change is more complex and cyclical, with changes in attitudes and beliefs stimulating additional changes in practice. Examining how changes in teachers' practice unfolded over repeated experiences with curriculum modules will perhaps lend insight into the complexity of changing teacher practice.

4 | METHOD

4.1 | Curriculum context

The AMP-IT-UP project was a long-term partnership between the Georgia Institute of Technology and a public-school system located in a rural-fringe, manufacturing region outside a major metropolitan area in the southeastern United States. The district serves over 11,000 students and consists of 18 schools (11 elementary, 4 middle, and 3 high schools), all of which are designated as Title 1 Schools. The findings presented in this article

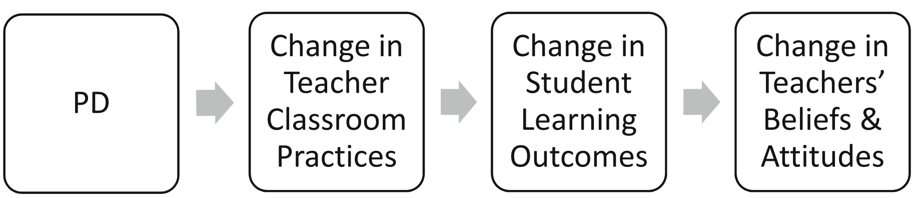

FIGURE 1 Guskey's model of teacher practice change. PD, professional development.

are drawn from data gathered at the district's four middle schools, all of which serve 6th–8th grade students and had participated in the project for at least 3 years. The district serves a predominantly low-income student population, with 67% of students qualifying for free/reduced lunch. The district is also relatively diverse, with subgroups including White (45%), Black (44%), Hispanic (7%), and Other (5%) students.

Informed by recommendations from Bybee (2010), the curriculum team was interested in whether and how providing short exemplar modules could have broader impacts on science teaching and learning, exemplifying what Bybee terms "introducing little changes with big effects" (p. 34). Thus, the project team focused on designing short curricular modules that were aligned such that students in the district's four middle schools would experience each of the three unifying practices at each grade level. The modules were iteratively developed by a university-based curriculum development team over the course of a multi-year effort that included multiple cycles of curriculum design, teacher PD and implementation. Over the course of curriculum development, teachers had multiple opportunities to provide feedback to this curriculum team through implementation surveys, classroom observation visits, and informal conversations.

A total of nine exemplar science modules were developed, including three modules each for earth, life, and physical science aligned to standards in 6th, 7th, and 8th grade, respectively. Modules were designed to be implemented in approximately one week, with each module structured around a contextualized challenge integrating standards-based content and the targeted practices of Experimental Design, Data Visualization, and Data-driven Decision Making. For example, in the 7th grade Oil Spill Challenge targeting Experimental Design, students develop an oil cleanup procedure to remove the greatest amount of oil in the shortest time possible. Over the course of the module, students develop procedures, carry out investigations and analyze data to determine what procedural improvements need to be made. An overview of

TABLE 1 Overview of AMP-IT-UP science modules

Title	Subject/grade	Integrative theme	Description
Lava Challenge	Earth Science/6	Experimental Design	Students engage as earth scientists to develop a procedure for measuring lava flow to help a town adjacent to a volcano develop evacuation plans in the event of an eruption.
Earthquake Challenge	Earth Science/6	Data Visualization	Students engage as earth scientists to plot and analyze earthquake data to help a company decide where to build its new cell phone manufacturing plant in northern California.
Winter Weather Challenge	Earth Science/6	Data Driven Decision Making	Students play the role of school officials and have to decide whether to close school or keep it open based on weather forecasts. Students are introduced to weather concepts and terminology and forecasting basics while learning how to read and analyze forecasts from the National Weather Service.
Oil Spill Challenge	Life Science/7	Experimental Design	Students engage as environmental engineers to develop a procedure that would remove the largest amount of oil from the ocean in the shortest time possible in the event of a large-scale oil spill.
Deep Sea Ecosystems Challenge	Life Science/7	Data Visualization	Students engage as scientists to analyze images of corals to evaluate the health of deep-sea ecosystems in the Gulf of Mexico after the Deepwater Horizon Oil Spill. The module helps students define and quantify data as well as differentiate between temporal and spatial data.
Coral Reef Challenge	Life Science/7	Data Driven Decision Making	Students engage as biologists advising the government and citizens of Fiji on recent acceleration in the death of coral reefs around Fiji.
Marine Snow Challenge	Physical Science/8	Experimental Design	Students engage as environmental engineers to develop a procedure to determine how the oil from the Deepwater Horizon spill landed at the bottom of the ocean.
Helmet Challenge	Physical Science/8	Data Visualization	Students engage as crash-test scientists for the SkateTech company to test helmets for skateboarders.
Marine Snow Challenge	Physical Science/8	Data Driven Decision Making	Students engage as product reviewers for the SkateTech company's website to review helmets for various abilities of skateboarders.

the science modules is presented in Table 1. The modules can also be downloaded at https://ampitup.gatech.edu.

While the modules represented a relatively brief intervention, the project envisioned the possibility of influencing teacher attitudes and practice beyond the implementation period. It was our hope that teachers' experiences with these exemplar modules would inspire not only continued module implementation beyond the formal partnership period, but also broader, sustained changes in science teaching practices. To this end, in addition to ongoing classroom-based support and summer PD institutes for teachers participating in the partnership, a sub-set of eight experienced science teachers (referred to as "focal teachers") participated in a lesson-redesign workshop focused on the revision of existing lesson plans to more closely resemble the science modules. Teachers brought lessons they planned to teach during the upcoming semester to this work session where they explored methods of shifting their existing activities toward becoming more inquiry based and in line with the integrative themes of the science modules.

4.2 | Participants

A total of 15 middle school science teachers participated in the study, including at least one and as many as six teachers from each of the four partner middle schools. As summarized in Table 2, teachers varied with regard to their previous teaching experience and their experience with the curriculum modules.

4.3 | Data sources and analysis

Teachers' attitudes and science teaching practices were explored using three data sources: interviews, classroom observations, and document data. Each of these data sources and procedures for data collection and analysis are described below.

4.3.1 | Interviews

Interviews were conducted with 15 teachers who implemented the science modules in their classrooms. All teachers participated in the first round of interviews, which was scheduled to follow teachers' implementation of the modules during the final year of project. These interviews were intended to gather teacher perspectives on the modules and how implementing them had influenced their practice at the conclusion of the RPP's multi-year curriculum development effort. A second round of follow-up interviews was conducted with six of the focal teachers, identified in Table 2, at the end of the subsequent school year, after the official project had ended. These follow-up interviews were intended to gather additional data on the ways in which the

TABLE 2 Participants' teaching and module implementation experience

School[a]	Teacher[a]	Total years teaching	Years teaching in district	Years teaching curriculum modules	Grades taught
School 1	Claire	2	2	2	6
	Diana	9	6	4	6–8
	Nancy[b]	3	3	3	7
	Kate	2	2	2	6–8
	Martha[b]	3	3	3	6, 7
	Deborah	4	2	2	8
School 2	Louise	12	3	2	7
	Lucy[b]	3	3	3	7
	Ruby[b]	5	4	4	6
	Cathryn[b]	6	4	4	8
School 3	Ruth	12	12	4	6
	Victoria	11	11	3	6
	Janet[b]	15	15	4	7
	Holly[b]	18	13	3	7
School 4	Joanne[b]	12	12	4	7

[a]Pseudonyms are used to preserve anonymity.
[b]Focal teachers.

modules had influenced science teaching practice and the degree to which shifts in practice endured beyond the end of the curriculum development project.

Interviews followed a semi-structured protocol in which teachers were asked to describe their approach to science teaching, to reflect on their experience implementing the curriculum modules and to describe any changes in their science teaching practices. Interviews lasted approximately 45 min and were conducted by one of four researchers in teachers' classrooms during their planning periods. Interviews were audio-recorded and transcribed. One interview was not recorded due to technical issues. Field notes were used to summarize this interview.

Interview data were analyzed using a sequential coding process (Miles et al., 2018), in which a start list of codes was iteratively applied, with codes being added, combined, or refined over several rounds of coding. The start list of codes included theoretical codes (Saldaña, 2015) representing the individual components of Guskey's Model of Teacher Change (PD, Teacher Practice, Student Learning, Teacher Beliefs/Attitudes). The code list also included codes aligned to each of the integrative themes for the curriculum modules (Experimental Design, Data Visualization, Data-Driven Decision Making) intended to identify instances in which teachers described instruction or expressed attitudes related to these practices.

Interviews were coded by two researchers using NVIVO qualitative analysis software. Following the initial development of the codebook, both researchers coded a common set of five interviews with agreement of 77% for this first round of coding. Following discussion in which code definitions were refined and clarified, the initial set of five interviews plus an additional three common interviews were jointly coded. Upon achieving 90% agreement, remaining interviews were divided between the two researchers for coding. After all interviews had been coded a first time, the two coders met to discuss and further revise the codebook to address ambiguities and potential themes or patterns.

4.3.2 | Classroom observations

One researcher conducted two rounds of observations in focal teachers' classrooms, one during the final, spring semester of the project ($n = 6$) and one the subsequent fall semester ($n = 5$). Observations were conducted by one member of the research team using a protocol adapted from the Electronic Quality of Inquiry Protocol (EQUIP) (Marshall et al., 2010), which was selected for its alignment with NGSS and previous use examining inquiry in science classrooms (Lotter et al., 2018). The EQUIP is a rubric-based protocol designed to measure the quality of inquiry instruction in K-12 math and science classrooms. The EQUIP defines levels of proficiency from Pre-Inquiry (Level 1) through Exemplary Inquiry (Level 4) for 19 constructs organized into four factors: Instruction, Discourse, Assessment, and Curriculum. In their validation of the EQUIP, Marshall et al. (2010) report strong face validity, high internal consistency (Cronbach's alpha, 0.88), and solid interrater agreement (85.6%). When scheduling observations, teachers were asked to identify a time where they would be implementing "typical science instruction." EQUIP ratings were supplemented by detailed field notes. Observation findings were contextualized using memos and reflections from the same researchers' informal observations of focal teachers as they implemented the curriculum modules over the previous 2-year period. Following the second round of observations, ratings for each EQUIP sub-scale at each time point, along with relevant field notes were compiled for each of the focal teachers.

4.3.3 | Document data

Interview and observation data were supplemented by document data from two sources: lesson planning documents, collected during the final semester of the project and during the semester following the project, and written reflections posted on the project's collaborative message board. The first set of lesson plans was collected from the five focal teachers as products of the professional learning workshop. The second set included "curriculum maps" presenting a sequence of standards and units at each grade level as well as lesson plans developed by individual teachers. The curriculum maps were developed by participating teachers enlisted by the district to create instructional resources for dissemination at participating schools. As part of their participation in the project, all teachers were asked to share their module experiences with colleagues teaching Science at other partner schools via a Google Groups site. We reviewed these responses to inform teacher interviews and to identify possible indications of practice change. Following coding and initial analysis of interview, observation, and document data, matrices were constructed to triangulate findings across data sources. These matrices synthesized observed and reported changes in teachers' science teaching following module implementation. The matrices were also utilized to create displays illustrating interconnections between PD, teacher practice, student outcomes, and teacher attitudes and beliefs.

5 | RESULTS

This research triangulates interview, observation, and document data to describe the ways in which implementing the modules influenced how teachers approach science teaching. Teachers' discussions of their practice include clear evidence that teachers intend to continue module implementation and numerous examples of both intended and enacted changes stemming from their participation in the project and experience with the curriculum modules. Teachers' descriptions of how implementing the modules influenced their approach to science teaching were reflective of four major themes: "revisiting" modules when teaching non-module science content, replicating particular activities within the modules, shifting teaching practices or revising existing lesson plans or curricula to more closely resemble the modules, and module implementation as a context for developing proficiency facilitating inquiry. Data related to each of these four categories of practice change are described below with additional illustrative quotations presented in Table 3, followed by findings pertaining to interconnections between teachers' experiences with PD and changes in teacher practice and attitudes.

5.1 | Revisiting the modules

In interviews and written reflections, teachers drew connections between the content or practices within modules and other science curriculum or standards they covered over the course of the school year. As in Cathryn's reference to the Marine Snow module below, teachers often described positioning modules as "prior knowledge" when introducing new content:

> Now, Marine Snow is the first one that we did. I used a lot of, 'Do you remember when we were doing the Marine Snow? How you took the data from your experiment, and you used it to infer what was happening to the actual organisms, and the effect that the oil had on it. Do you remember how you did that?' They're like, 'Yes, we remember how we did that,'...We referred back to that a lot.

5.2 | Replication of module activities

Teachers also described how they replicated or continued to use specific module activities as they taught other science content. Teachers' descriptions of these adaptations tended to center on one or more of the NGSS-aligned practices around which the modules were organized

TABLE 3 Illustrative quotations: Shifts in science teacher practice and attitudes

Theme (numb of teachers)	Illustrative quotation
Revisiting modules (8)	I will refer back to the Deep Sea module during standard 4.c. This is a great example of limiting factors, and human impact on an ecosystem. (Martha)
Replicating module activities (6)	I will utilize the video included with the module and reference information included in the module booklet. (Claire)
Revising existing lesson plans/ curricula (11)	I think AMP provides a way for us to look into other parts of the curriculum and say, 'How can I bring the lab and make sure that the students are hands on, they're on the computer, or they're finding research, or they're putting it all together, tying everything to the big picture?' (Nancy)
Developing proficiency facilitating inquiry (6)	I thought there was only a couple different ways you could do it to get the data for the lava challenge, but they did so much more than that...of course, we gave them only the set materials, but they were reaching into their book bags to grab other materials to use like pencils. They broke up pencils to put in the way of the lava because they were like, 'The landscape's not flat.' So I said, 'Okay.' I was looking at it first like, 'Why are you doing that? You're making it more of a mess.' That was my teacher brain. But then I went, 'wait a second,' they told me to step back and so I did and the learning was just amazing. (Martha)
Sustaining module implementation (13)	So I think it's a great program. I do plan on continuing to use it because I think the students can gain so much in one week that might take us longer to cover. I think it's building the possibilities that they can do because sometimes we limit our students with just old school teaching. (Nancy)
Student outcomes inform changes in practices and attitudes (12)	I think it's a breath of fresh air. It's nice to have this stuff prepared for you and it incorporates a lot of good skills that help you learn a lot about your students. And then I think it gives you a mindset too if you see this really worked for this class I need to do more things like this. And then you can use that as a guideline for writing future plans. I think they really can function as guidelines and then you learn a lot and the students learn a lot of valuable skills that I think you wouldn't necessarily think to incorporate when we're really focused on content and not broader aspects of science. (Lucy)
Shifting practices and attitudes through PD (8)	I think the training that occurred at the beginning of the school semester, that was helpful of being able to actually go through each module and see how it was designed to be implemented, that was helpful for me, so that I could just directly model that within the classroom. (Claire)

(experimental design, data visualization, and data-driven decision-making). For instance, in the project's online forum, Ruth described how she adapted lessons on tides to include data visualization, stating "I revisited data visualization when I taught tides. Students had to plot tidal heights and then analyze the patterns found in the data." Similarly, consistent with module activities requiring students to design procedures for investigations, after implementing the Oil Spill module, Lucy posted that "students will continue to develop their own procedures during future labs as well as in regular classroom activities and performance tasks."

5.3 | Shifts in science teaching and curriculum revision based on modules

In addition to referencing particular instances of module adaptation, teachers reflected on how their experiences implementing the modules and participating in the RPP generally precipitated more global shifts in how they approach teaching science. Although teachers occasionally noted individual modules that were particularly influential for their practice or that they were especially likely to continue implementing, teachers generally reflected on the cumulative effect of module implementation on their practice. For instance, one first year teacher, Claire, described how the modules informed her science teaching goals:

> I think the AMP modules are definitely the direction I'm headed towards. Of course, I'm not there completely with every standard, but I would like to model every lesson in my class, if possible, more closely to how AMP is presented where they're given a challenge and they have to figure things out, decipher information, develop procedures… all of those things, I think are aligned to where I want to be professionally as a science teacher.

Similarly, as in the following excerpt from Martha's follow-up interview, several teachers shared their perspective that the modules were on the forefront of "where science education is headed":

> It definitely does influence the way you teach because you shift your focus from the content to the cross-cutting concepts, how to think versus what to think. And so, I found myself using those as models to create my five-E lessons, starting with some sort of creative challenge and building off of that. And so, I've used it throughout the past three years basically as a model. And I remember going to the first AMP training and thinking, 'Wow. This is where science education is headed' and I want to jump straight into it. So, I've been trying to make that as a basis for a lot of my lessons.

This teacher's decision to pattern her lesson plans on the modules illustrates a general trend we saw in teachers using their module experience as the basis for curriculum revisions. Interestingly, although some discussion around curriculum revision naturally came from teachers like Nancy who participated in PD sessions explicitly encouraging revisions, a number of other teachers spontaneously saw the project as an opportunity to re-examine lesson plans beyond the modules.

The lessons teachers revamped during the lesson re-design workshop were not always implemented and varied in the degree to which they exemplified the integrative themes of the modules. Although the changes teachers made to their lesson plans tended to be relatively minor, we did discern efforts to incorporate aspects of the modules. For example, several teachers replaced prescriptive lab procedures with graphic organizers to support students as they developed their own procedures. Classroom observations also confirmed that teachers were engaged in inquiry-oriented activities resembling aspects of the curriculum modules. Teachers generally maintained or increased ratings on the EQUIP protocol from the first to the second observation, with all five teachers who participated in follow-up observations scoring at the proficient or exemplary inquiry levels on all EQUIP factors (Table 4). Observation field notes indicate that teachers' proficient or exemplary ratings on the Instruction and Curriculum factors were often attributed to teaching practices and activities closely resembling or directly patterned on the modules. For example, fieldnotes taken during the second observation in Holly's classroom state that the observed lesson "has a strong inquiry focus, includes procedure writing, data analysis, hypothesis development, and relates to important content…students were engaged in an activity in experimental design (similar to AMP)."

5.4 | Developing proficiency facilitating inquiry

Interview data suggest that module implementation also served as a context for developing proficiency facilitating inquiry. Both novice and experienced teachers shared

TABLE 4 EQUIP observation protocol ratings for focal teachers

	EQUIP factors									
	Instruction		Discourse		Assessment		Curriculum		Overall rating	
Teacher	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
Holly	2	4	2	4	2	3	2	4	2	4
Cathryn	3		3		2		2		3	
Nancy	3	4	3	3	3	3	3	3	3	3
Martha	4	3	3	3	3	3	3	4	3	3
Lucy	3	4	3	4	3	3	3	4	3	4
Janet	3	3	3	3	2	3	3	3	3	3
Average rating	3.0	3.6	2.8	3.4	2.5	3.0	2.7	3.6	2.8	3.4

examples of ways in which facilitating the modules strengthened their ability to engage students in inquiry. For example, an early career teacher, Martha, described how enacting the Lava Challenge helped build her confidence for facilitating investigations:

> I did not do any labs with my students ‘cause I was almost afraid that classroom management would be terrible… then, when I go and actually do the first module, they're more engaged than I thought they would be, so then I start doing more investigations. It kind of gives you the confidence, ‘cause after you do the Lava Challenge and you're like ‘oh, everything turned out fine’, you're like ‘maybe I can do more complicated labs.’

More experienced teachers highlighted how specific elements of the curriculum prompted examination of their approach to inquiry. For example, referring to the Depth of Knowledge (DOK) levels of questioning, Deborah discussed the level of questioning in the module materials and noted, “it has made me more cognizant of my own questioning during investigations. Am I getting in those DOK threes and fours questions? It's caused me to stop and think.”

5.5 | Student outcomes inform changes in practices and attitudes

Consistent with the Guskey's model, our interview data indicate teachers' attitudes about the modules and commitments to changing their practice were primarily informed by their observations of module outcomes. When discussing student outcomes, teachers reference both student engagement and learning outcomes and were far more likely to discuss positive outcomes than negative outcomes, which were quite rare within the dataset. As in Martha's account of student engagement exceeding expectations during the Lava Challenge above, teachers frequently shared their observations that students were more engaged during the modules than they expected, sometimes indicating that this level of engagement motivated them to continue implementing the modules or try additional module-like activities with their students.

For some teachers, observations of student learning during module implementation made a long-lasting impression that they continued to reflect on in subsequent years. For example, in her follow-up interview conducted a year after she initially described her initial implementation of the Lava Challenge, Martha continues to reflect on that early experience in vivid detail:

> Like I said, my first year when I taught sixth grade science and implemented those, after they went so well, I think unintentionally I said, ‘I want to see more of this in my classroom.’ So, the next year I started implementing it even more. My first couple years, teaching it was difficult to be hands-off and let the students really think through the challenges. As a teacher you kind of want to go and fix their learning. I think the one that really got me there was the Lava Challenge in sixth grade. At first, I would try to go and fix their design of their experiments, but then I realized after the first class period that is not what I was supposed to be doing, and after I left them go and do then I just saw so much more learning take place, and I saw their creativity just blossom. So, they were coming up with designs for that experiment that I never would have thought of.

Like Martha, a number of teachers shared their observations in specific terms, highlighting exactly what they saw that indicated student learning and engagement. Consider, in the following example, how Nancy frames the success of module implementation in terms of student learning outcomes, repeatedly highlighting what she *saw* in her classroom:

> I think once you do the first one, you see the impact it has on their learning. So, I would say as a new teacher, I did see it in two grades, so sixth and seventh grade, earth and life science. I saw how it connects to the lesson. I saw where it takes away from maybe a PowerPoint or a direct instruction, and it ties in so many components the students need. It has that real-world aspect. It has hands on learning. And it has a constructed response, a writing component. So, you see how they're processing, you're seeing the connections they're making, you're allowing them to see potential jobs out there in the real world.

When asked to describe an example of successful module implementation, teachers were far more likely to discuss how their students responded than what they did to successfully facilitate the module. For example, asked to recount a successful experience teaching the modules, Claire shared the following account of student engagement during an experimental design module:

> Just hearing the students, just giving the ideas, and together as a whole developing a unified procedure without me having to really do anything. That was a success because I would say 95% of the students were engaged and students who usually are a little intimidated or are timid, they were raising their hand, giving their ideas.

Thus, for Claire, successful implementation was more about student actions (raising hands, sharing ideas, voting) as they worked collaboratively to develop procedures than about the particular instructional moves she made to facilitate the module.

Teachers also described how their observations of how the modules worked in their classrooms informed subsequent module implementations. In these descriptions, teachers shared lessons learned about aspects of the modules they would continue implementing as well as aspects that they did not believe would work well for their students. For example, in one follow-up interview, Martha describes how she decided to forego implementing the Oil Spill challenge with a certain group of students based on her concerns about classroom management:

> The Oil Spill challenge would have been very difficult to implement with them...we just have a very odd group of kids that have a lot of negative behaviors this year...so I just decided that my classes probably could not of handled it, so I decided not to do it this year.

Although teachers described occasional adaptions or certain modules they were less likely to implement than others, follow-up interview data confirm that, in each partner school, teachers expect to continue implementing the modules for the foreseeable future. These follow-up interview data and curriculum planning documents provided by teachers described a range of strategies for integrating the modules into their existing curriculum. Teachers discussed plans for training new teachers at their schools to implement the modules, with several teachers noting that these efforts were underway. Following the project, the district invited teachers at each grade level to help develop curriculum guides laying out the scope and sequence of instructional activities for the following school year. According to these documents, at each grade level, the curriculum modules would be implemented either as an introduction or supplement to existing curriculum units, sometimes being adapted to serve as a performance assessment.

5.6 | Shifts in practices and attitudes through PD

Just as teachers' perspectives on the modules were influenced by their observations of student learning and engagement, a number of teachers discussed how they initially formed positive impressions of the modules during PD, and especially through activities in which they were positioned as learners to work through the modules themselves.

> The classes have helped, they really helped, so I could be familiar with them and do it ourselves. That helped me with familiarity and the confidence and everything. Because if I had not done it, I'd be like, 'I don't know if this is going to work', even though you know, I have the teacher's manual and I can read over it, but having actually done it as if I was a student, and seeing how fun it was

> and how it even made me think about the concepts...I felt better about my students getting it after I got it, you know? And I wasn't really all that that surprised when it worked well for them, 'cause it was even fun for me.

Like many of our teachers, Victoria's initial positive impressions were reinforced by observations of positive student outcomes when she "wasn't really all that surprised" that the modules worked well for her students. Thus, although teachers' observations of student success with modules were the most powerful influence on their attitudes and practices, positive initial experiences with the modules in PD sessions primed teachers to embrace shifts in their practice.

6 | DISCUSSION

Teachers' accounts of their experience with the modules and corresponding shifts in their teaching practice highlight a number of ways in which teachers act as agents of curriculum adoption and adaptation. For some teachers, the curriculum modules served as a sort of touchstone, a learning experience they referred to and, in some cases, built upon when teaching other content. Other teachers saw the modules as a template for revamping existing lesson plans or creating new investigations for their students. In other cases, implementing the modules provided an opportunity for teachers to develop confidence in their ability to facilitate inquiry, leading to new possibilities for science learning in their classrooms. Given the various shifts in teacher attitudes and practice we observed, the week-long AMP-IT-UP modules serve as an example of the type of "little changes with big effects" promoted by Bybee (2010).

By following up with teachers in the school year after the project's formal conclusion, the study provides an example of durable changes in teacher practice facilitated by an RPP while also affirming the importance of teacher agency for enduring curriculum reform (Debarger et al., 2017; Parke & Coble, 1998; Penuel & Gallagher, 2017; Severance et al., 2016). The changes in teacher practice apparent that following year included both spontaneous efforts to replicate or adapt the modules by individual teachers as well as more coordinated efforts to institutionalize certain modules within grade-level curriculum resources used district-wide. The strong, longstanding partnership with the district and teachers' involvement in the iterative design of the modules over several years enabled continued, widespread integration of the modules or aspects of the modules into science instruction. Although the project is gratified that teachers continue to implement certain curriculum modules as written, it is perhaps more noteworthy that many teachers have extrapolated key aspects of the modules, such as approaches to facilitating data visualization or strategies for having students design their own investigation procedures, as they have adapted or created new lesson plans. In addition to individual teachers' inclinations to continue implementation, the strong investment in the AMP-IT-UP curricular modules at the school and district levels cultivated through the RPP echoes previous work describing the role of supportive contextual factors for adoption and implementation of curricular innovations (Century & Cassata, 2016; Hayes et al., 2017; Knapp & Plecki, 2001; Lumpe et al., 2000).

Consistent with Guskey's (2002) model of teacher change and previous work examining factors influencing the development of teacher practice (Hayes et al., 2017; Klinger, 2004) and beliefs (Luft, 2001; Lumpe et al., 2000; Marco-Bujosa et al., 2021), teachers' accounts indicate that shifts in practice and attitudes regarding the modules followed from observations of student success with the modules rather than directly from PD. Importantly, this is not to say that PD was not an integral part of teacher development. Indeed, for a number of teachers in our study, positive impressions of the curriculum formed in PD seeded initial motivation to implement the modules. Teachers' enduring commitment to module implementation and more global shifts in mindsets and practices then developed through teachers' observations of student outcomes. These findings suggest the possible need for models of teacher development to distinguish between teachers' initial motivation to try new practices and more lasting shifts in teacher practice and attitudes. Additionally, reflections from teachers who had implemented the modules for several years underscored the cyclical nature of practice change. Specifically, teachers described how initial shifts in practice in order to implement modules spurred adaptations and refinements in subsequent module implementations, which then precipitated positive student outcomes, shaping teachers' attitudes about the modules and integrative themes and, subsequently, further changes in practice.

7 | LIMITATIONS

Although our interview data provide insight into teachers' attitudes and beliefs related to the modules and how they influenced science teaching practices, the study's reliance on interview data necessarily limits our ability to report definitively on the extent to which implementing the modules inspired enduring changes in teacher practice. Although teachers had nothing to gain from falsely reporting shifts in practice, we acknowledge that teachers' accounts of their practice may have been incomplete. Further, due to time and resource limitations, we were not able to conduct extended classroom observations that, perhaps, would have allowed for a more systematic study of teaching practices during and following teacher participation in the project. Additionally, without observation data documenting teachers' practices prior to the project, we cannot necessarily draw definitive conclusions about changes in teacher practice. The study is also somewhat limited by the scope of follow-up data collection. Although we were able to conduct follow-up interviews and observations from a smaller focal group of teachers, we cannot necessarily determine the degree to which these teachers' experiences are reflective of all of the teachers who participated in the AMP-IT-UP project.

8 | CONCLUSION

Results from this research highlight possibilities for influencing sustained change in teachers' attitudes and teaching practices through innovative NGSS-aligned curricula and PD. Although the scope of the science modules was somewhat narrow, comprising a few weeks of instructional time, data suggest that teachers may have begun to extrapolate aspects of the approach underlying the modules to other facets of their science teaching. Thus, the study illustrates how, even after formal partnership work concludes, curricular interventions can leave an enduring mark at the classroom level through changes in teacher practice. Although our findings are drawn from a sample of teachers participating in one RPP, we hope this work will be of interest to a broad audience of researchers and teacher educators invested in the hard work of fostering durable changes in teacher practice through RPPs.

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