MISSISSIPPI ACADEMY FOR SCIENCE TEACHING (MAST):

FINAL EVALUATION REPORT

2017

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Acknowledgements

MAST has required a tremendous team effort from Jackson State University faculty, staff and Rockman et al. Many thanks to the participating teachers in Mississippi for sharing their time and eagerness to learn, and thank you to the PD instructors for their expertise and talent. Thank you to the many JSU faculty members from the Physics, Atmospheric Science & Geosciences who participated in the administration and execution of this particular project for so many years. A special thank you to my Rockman colleagues who have worked on this project since 2009. Working on MAST has required intense collaboration and has been an invaluable learning experience for all. Lastly, thank you to Mehri Fadavi, MAST's Principal Investigator, for your vision.

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Executive Summary

The Mississippi Academy for Science Teaching (MAST) is a program funded by the National Science Foundation (NSF) to provide pre-service and in-service high school teachers with content and pedagogical support in science. The content taught in MAST is tied to the content objectives of the 2010 Mississippi Science Framework, and provides teachers with the knowledge and resources to better understand and teach these objectives. MAST involves participation in an intensive three-week summer workshop, as well as supplemental courses and program staff support throughout the academic year. This report serves as a summary of findings obtained between 2009-2017. The summary includes both short-term impacts on teacher and student outcomes, as well as MAST's long-term impact on past participants; it also examines whether or not the short-term professional development (PD) gains have staying power (> one year later), as indicated through self-reported data.

Our previous eight evaluations have shown short-term, small-to-moderate significant improvements in the following areas: a) confidence in knowledge (teachers and students), b) confidence in teachers' use of MAST pedagogical techniques (e.g., inquiry), c) personal science teaching efficacy, and d) science content knowledge. Our findings have also demonstrated that MAST has the ability to promote long-term changes in teaching practices.

The findings indicate that, with regard to MAST teachers' ability to teach science and their confidence in physical science content knowledge, teachers exposed to MAST showed greater gains compared to teachers not exposed to MAST (control group). Additionally, MAST can achieve meaningful and sustained impacts on participants' teaching and learning, including: a) their approach to teaching science and overall teaching practice, b) their levels of confidence in teaching and learning science, c) their levels of comfort in teaching the 2010 Mississippi Science Framework, and d) their students' knowledge, confidence and learning of science. Teachers showed greater gains in content knowledge, teaching efficacy, and confidence in teaching science as compared to the control group. This study documents how teachers who participated in MAST continued to implement the principles of the program years after their participation had ended. Rockman et al (REA), a San Francisco-based research and evaluation firm that has served as the program's external evaluators since 2009, conducted each annual evaluation of the program's impact. Our analysis of the data collected leads to several main conclusions and lessons learned:

1. Effective implementation of the MAST model involves learning over time, trust building, and comfort with the material. Research on quality PD focuses on the approach that teachers must take when learning new teaching strategies and new material – viewing

PD as a process and complex system rather than an event that leads to rapid change. As we have demonstrated with the Alum findings, over time, teachers had time and greater confidence in implementing what they've learned from MAST. While some short-term gains have been found from teachers and students, the long-term changes demonstrated by the alums show that the program has lasting effects. In addition, according to Miller et al. (2015), extended PD of several years allows participants to build trust with other educators, expand networking, and heightened comfort with new strategies and material. More time to learn, more time to engage in peer-to-peer reflection and observations, increased feedback, and more time to implement change may lead to stronger outcomes.

2. Learning from experts is essential to teacher and student benefits. Banilower et al. (2007) argued that students' ability to learn science depends on teachers' advanced content knowledge and their ability to convey information in developmentally appropriate ways. Without expert knowledge and insight, teachers might be constrained in developing scientific engagement and thinking.
3. Teachers must learn from one another to improve practice. MAST teachers often discussed the importance of peer-to-peer learning and interaction, collaboration, and reflection. High school teachers may become accustomed to working independently when it comes to teaching and managing their classes. MAST incorporates and encourages reflection, small-group projects, and candid discussions about teacher practice and how to best approach student learning unique to the state of MS. In this learning environment, teachers participated in professional learning communities with a shared understanding of their long-term teaching goals – to improve student outcomes and achievement.
4. Teachers can demonstrate competency, mastery, and growth in a variety of ways. MAST has proven the long-standing argument that there is not a "one-size-fit-all" approach to PD, teacher learning, and effective practice. MAST gave teachers the freedom to customize their learning in a way that suited them and, importantly, their students. Teachers have demonstrated growth in a number of areas, including content knowledge, teaching efficacy, learning efficacy, and professional learning practices with gains in some areas but not others.
5. Post-program support and outreach could maximize teacher and student impact. The MAST alums provided the strongest evidence of the program's long-term impact. Some of the most frequently cited requests from the program, years later, were the inclusion of post-program support, outreach, and networking. If MAST wants to further develop its long-term impact on educators in MS, perhaps an online forum for teachers to share experiences and practices that work would yield greater confidence and support. Opportunities such as the MAST "mini conference" (lead by MAST alums for teachers) offers such experiences.

Our report concludes with a final discussion on the future of the MAST model.

Background

MAST was funded by the Math and Science Partnership (MSP) program of the NSF in 2008. The vision of this MSP grant is to improve the teaching and learning of mathematics and science throughout the state of Mississippi. Specifically, the mission of MAST is to improve educators' science content knowledge and teaching efficacy in high school physical, earth, and space science. MAST served as a continuation of five previous Mississippi MSP grants: the MAST I, II, III, MAST 4U, and MAST5 programs funded from 2004-2013 by the Mississippi Department of Education. Currently, MAST's core professional development (PD) model has been adopted for the following two programs: Mathematics Advancement in Teaching Through Professional Development (MAT-PD), also funded by the Mississippi Department of Education in 2013, a math PD program for elementary and middle school math teachers in Mississippi; and Institutional Change Through Faculty Advancement In Instruction and Mentoring (ICFAIM), funded by the NSF in 2013, a PD program designed to increase the retention of undergraduate students in the College of Science, Engineering, and Technology by improving the teaching and mentoring of undergraduate science faculty and graduate students at Jackson State University (JSU).

MAST implements its objectives by engaging teachers in four weeks of graduate coursework on content and pedagogy in science (three weeks in the summer, five Saturdays during the school year). Teacher participants in this learning environment must assume and play dual roles – as teacher and as learner. During these graduate-level classes, teachers learn physical, earth, and space science through a combination of lectures and high-school level hands-on activities. While MAST programming has focused on the Mississippi Curriculum Framework objectives (aka, MAST "Big Ideas"), the instructors and sessions have varied slightly each year based on participants' needs and interests.

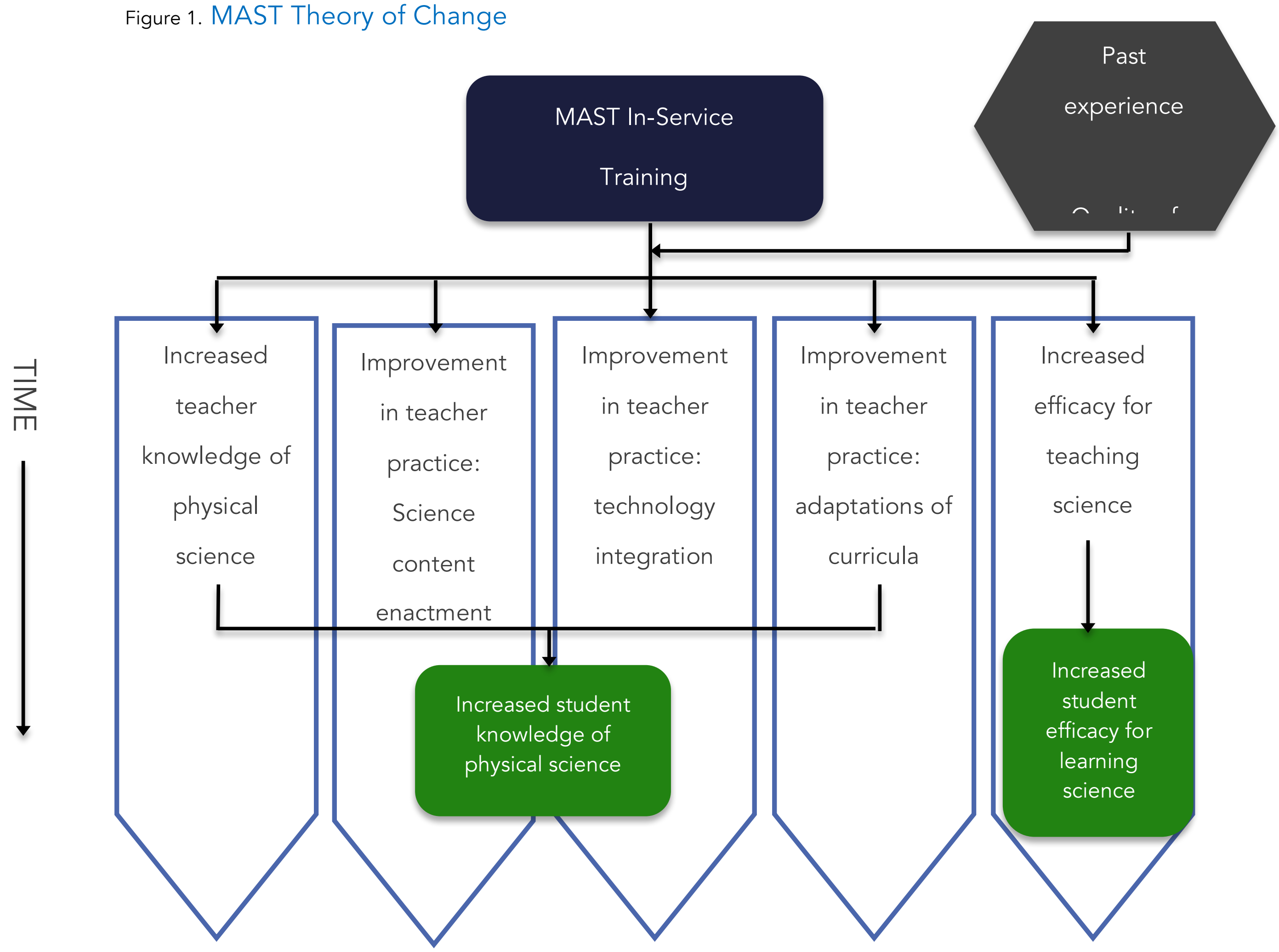
After the workshops, teachers received all the materials they had used, so as to allow them to take back to their students what they had learned. They also received:

- Membership in the National Science Teachers Association (NSTA) and the Mississippi Science Teachers Association (MSTA), and travel stipends to those organizations' conferences;
- Tuition for two graduate courses worth $2000; and
- A stipend of $4000 for successful completion of the program.

During the school year, teachers also received visits from MAST program staff, whether to observe and/or support teaching, or to bring to classrooms novel instructional technologies (a portable planetarium, iPods and then iPads with science podcasts). This combination of graduate courses, instructional materials, and classroom visits was expected to lead to short and long-term improvements in teachers' content knowledge and teaching efficacy, and ultimately to growth in student content knowledge and positive attitudes toward science.

In 2008, evaluators worked with the MAST principal investigator to construct a theory of change model (Weiss, 1995) that defined the relationship between the project's activities and outcomes (Figure 1). The program was expected to: (a) enhance teachers' content knowledge, instructional practice, and confidence for teaching science, and (b) demonstrate changes in teacher outcomes would subsequently lead to improvements in students' content knowledge and attitudes toward science. We recognized that the magnitude of these changes would vary by teacher. Hence, the MAST model acknowledges that teachers' prior knowledge, attitudes and experiences as well as their perceptions of the quality of the PD may mediate MAST's eventual impacts.

Figure 1. MAST Theory of Change



Evaluation Overview

Our evaluation data from previous years have demonstrated the following trends: Project MAST helps give teachers strategies and materials that they use in their classrooms in an effort to engage students in hands-on learning. The program has had a positive impact on the knowledge and teaching practices of in-service K-12 teachers, short-term and long-term.

Evaluation metrics during previous cohorts included measures of teacher attitudes towards science, student attitudes toward science, and teacher and student content test results. Over the years, results have shown small to moderate improvements among teachers in the following areas:

- Confidence in knowledge of physical science, earth science, and astronomy
- Confidence in using MAST pedagogical techniques (e.g., inquiry)
- Personal science teaching efficacy
- Science content knowledge

Teachers also reported using MAST strategies and MAST materials for teaching inquiry – evidence that MAST has influenced teachers' classroom practices, years after participating in the PD.

Collectively between 2009-2017, student results showed small, significant gains in the following areas:

- Confidence in knowledge of physics and earth science
- Physical science content knowledge (Misconceptions-Oriented Standards-Based Resources for Teachers (MOSART) and Mississippi Department of Education practice exams), group-level gains

Thus, Project MAST's professional development model has been successful in producing most of its desired results. Table 1 summarizes our evaluation activities and impact between 2009-2017, and our ability to include control group data and comparisons during that time frame. Table 2 summarizes our evaluation activities and impact between 2014-2017. Importantly, with more staff capacity and funding, we are able to include control group data and comparisons in the current study during the past two years.

Table 1. Project MAST 5-Year Impact Evaluation Matrix – In-Service Component (2009-2017)

Impact Results that the program has achieved thus far	Indicator How we know that the project has achieved the impacts	Measures/Data What we used to measure progress towards reaching the impact goals and objectives
1. Increased knowledge in physical, space and earth science	• Greater gains from pre to post in teacher content knowledge compared to a control group[1] • Change in perceptions of knowledge	• Pre and post content knowledge test for teachers • Pre and post teacher surveys • Teacher interviews
2. Improvement in teacher practice: science content enactment	Teachers demonstrate enactment, defined as: • Use of MAST (or MAST-like) materials as opposed to materials used previously • Use of MAST pedagogical strategies (e.g., inquiry) as opposed to strategies previously used • Use of MAST learning goals as opposed to learning goals previously used	• Guidelines given to instructors • Observation of MAST workshops • Pre and post-MAST lesson plans • Post teacher survey • Post teacher interview • Classroom observation
3. Improvement in practice: science technology integration	• Use of MAST technology materials as opposed to technology previously used	• Same as above
4. Improvement in practice: adaptations of curricula	Use of MAST adaptation strategies in teaching: • The same content in which the strategy was modeled.[2] • Different content in which the strategy was modeled[3]	• Same as above
5. Increases student content knowledge in physical, space and earth science	• Greater gains from pre to post in student content knowledge compared to a control group	• Student content knowledge test
6. Increased science teaching and learning efficacy	• Greater gains from pre to post in science teacher efficacy compared to a control group • Self-reported gains in efficacy for teachers • Greater gains from pre/post in student efficacy	• Pre and post survey for teachers • Adapted version of STEBI (Science Teacher Efficacy Beliefs Instrument)
7. Increased knowledge of the MAST program by school administrators	• Gains in perceived knowledge, appreciation, and support by participants	• Teacher post survey • Admin post seminar survey • Administrator and teacher interviews

[1] Due to staff capacity, staff turnover, and funding we were unable to utilize control groups until the Fall of 2015.
[2] For example, in the Newton's First Law workshop, the instructor talks about accommodations for English language learnings. The teacher uses those accommodations in his/her lesson on Newton's First Law.
[3] For example, in the Newton's First Law workshop, the instructor talks about accommodations for English language learnings. The teacher uses those accommodations in the lesson on planetary motion. Furthermore, the workshop on planetary motion didn't include information on accommodations, so the teacher must have learned about accommodations in a different lesson.

Table 2. Project MAST Extension Activities – In-Service Component (2014-2017)

Extension Interval	Indicator How we know that the project has achieved the impacts	Refined Evaluation Activities with same SOW
Extension 1 (Year 6): August 2014 – July 2015	Review of MAST impacts to refine model to reflect teachers' needs: • Originally proposed MAST impacts (summarized in Table 1), as they compare to current literature • Long-term impact of MAST (Alum study, 2015)	• Literature review • Interviews with MAST alums • MAST alum post (longitudinal) surveys
Extension 2 (Year 7): August 2015 – July 2016	Exhibit and illustrate greater gains/ enactment/ adaptation in all indicators (summarized in Table 1), incorporate findings from literature review and long-term impact of MAST (Extension 1), and test refined model through the following activities: • Resume MAST summer workshops for two groups: - MAST alums - New cohort of MAST teachers • Recruit and accept "control group" teachers from the Jackson Public School District in an effort to compare "MAST exposed" teacher findings to "non-MAST exposed" findings. • Hold summer workshops for control groups	• Revisit original MAST PD model and make refinements • Dissemination of Alum Study findings • Prepare and administer pre/post data testing of control group, Alums, and new cohort • Guidelines given to instructors • Observation of MAST workshops • Pre and post-MAST lesson plans (beginning of 2015 academic year, and end of 2016 academic year)
Extension 3 (Final – Year 8): August 2016 – August 2017	Exhibit and illustrate greater gains/ enactment/ adaptation in all indicators (summarized in Table 1), incorporate findings from literature review and long-term impact of MAST (Extension 1), and test refined model through the following activities: • Collect pre and post data from the summer 2016 cohorts (alums, control groups, new cohort) • Final analysis of Extension 2 pre (Fall 2016) and post (Spring 2017) data	• Post teacher surveys • Post teacher interviews • Classroom observation • Data analysis • Final report

Having conducted evaluations of MAST and its variants over the past eight years, Rockman and the MAST leadership believed in the potential value of an investigation of MAST's impact in comparison to teachers who have not been exposed to MAST. In 2016, participating teachers for the current evaluation: a) graduated from the MAST program between 2004-2013 (4-8 grade science teachers) and 2008-2014 (9-12 grade science teachers); b) have not been exposed to MAST but teach in the vicinity of Jackson, Mississippi; and c) are a new cohort of incoming science high school teachers. Using control group data, we addressed the following research questions.

Research Questions (2008-2017)

- Quality of implementation. How do teachers engage and respond to MAST programming? What elements of the program do they find most and least valuable and why?
- Teacher impacts. To what extent do teachers who participate in MAST demonstrate growth in (a) teaching practice and (b) self-efficacy for teaching?
- Student impacts. To what extent do the students of MAST teachers improve their self-efficacy for learning science and content knowledge?
- MAST teacher and student outcomes vs. control group outcomes. How do the outcomes of teachers exposed to MAST compare to those *not* exposed to MAST?
- Long-term impacts. Does the MAST program affect the long-term teaching and learning of in-service teachers who participated between 2004-2013? What effect did teachers think the PD program had on them years after the fact? Do certain external factors, such as participation in other similar PD programs, play a role in the program's long-term impact?

Summary of All Evaluations

Evidence previously collected from all REA evaluations has shown that MAST participants have gained in science content knowledge, pedagogical content knowledge, confidence, and teaching efficacy, and have expanded their teaching practices and in-depth conversations with teachers. We now have evidence of these findings in comparison to a control group, and evidence of these findings shown with program alums. The program has shown that it can be beneficial for teachers' short-term *and* long-term professional growth, as shown by who have returned to MAST after several years. Our evaluations have provided a unique opportunity to understand MAST's impact on teachers' attitudes and teaching practices in comparison to teachers who have not started MAST.

To date, we've had the opportunity to analyze data from various subgroups of Mississippi teachers who participated in MAST: Alums, Annual cohorts of new participants, and a Control group.

MAST Alums

While it is difficult to examine what outside factors, over time, may have affected past participants' feelings related to MAST having improved their teaching and knowledge over time, it is significant to note that based on our previous Alum Study in 2015, the positive feedback and reported impact of the program remains over a long period of time. In response to this positive feedback and evidence of long-term impact, MAST leadership developed PD courses specifically for MAST alums that integrated more advanced science content and science teaching strategies.

New Cohort of MAST Teachers and Control Group

Our 2016 evaluation for the new cohort of MAST teachers included:

- Implementing a refined PD model for past participants and the new cohort, based on previous MAST alum findings and suggestions.
- Evaluating teacher outcomes from MAST alumni from 2015 summer workshops in addition to a new cohort of teachers, and
- Using a randomly assigned control group of MAST teachers accepted to the program to compare teachers exposed to the new alumni PD workshops to those not exposed. The control group will experience "delayed exposure" to the new MAST alumni workshops (or intervention) and start MAST the following summer.

Literature Review – Principles of Effective PD

For science domains, K-12 science educators in the U.S. are encouraged to take a more rigorous approach with their teaching and PD. Prior to 2001, literature on PD for K-12 teachers focused on PD as a key determinant in improving teacher satisfaction, underscored by the belief that teaching practices and student performance improve as a result (Cohen & Hill, 2000; Darling-Hammond & McLaughlin, 1995; Elmore, 1997). The recent push for teacher development was fueled by the 2001 No Child Left Behind Act, which mandated that teachers receive quality PD to supplement their practice. As of 2008, 48 out of 50 U.S. states require six hours of PD every year for five years before renewing their teaching licenses, and most states require 120 hours of PD over a 5-year period (Yoon et al, 2008; Loeb, Miller, and Strunk, 2009).

As reiterated by the National Research Council (NRC), effective instruction is paramount in promoting students' conceptual understanding of science (National Research Council, 2006, 2007, 2011, 2012). Almost two decades after the National Science Education Standards (NSES) were introduced by the National Research Council in 1996, high school science instruction in the U.S. still has not successfully created learning environments where: a) the needs of diverse learners are met, and b) students are engaged with science (El-Hani & Mortimer, 2007). The movement toward "reform-based" science teaching has been restricted mainly because teachers must be knowledgeable about science content in addition to science pedagogical content (Penuel, Gallagher, & Moorthy, 2011; Vaughn et al., 2011), and teachers must learn new skills to implement reform-based practices. To the present time, however, despite demonstrations that high-quality PD can provide support and guidance for teachers in need, little is known about the effectiveness of science PD in terms of fostering long-term change.

Numerous research studies have outlined key aspects of effective PD (for review, see Gusky, 2003), and many of these show overlapping characteristics and solutions for strengthening secondary science instruction. In "What Makes Professional Development Effective," Garet (2001) argued that the more common approaches to teacher PD, such as taking course taught by experts and expecting pre and post gains, are becoming less popular despite their widespread use. PD that includes mentoring and study groups is becoming the norm for change in teacher practice (Garet, 2001; Ingersoll and Strong, 2011). In support of this argument, in "Teacher Professional Development: It's Not an Event, It's a Process," Harwell (2003) argues that "professional development in which participants are given the opportunity to learn new classroom practices in similar contexts that those practices will be used is far more effective than more traditional methods of PD (Harwell, 2003, page3). Using a less process-oriented approach, Yoon et al. (2008) identified five specific criteria that constitute "high quality" PD:

1. It is sustained, intensive, and content-focused.

2. It is aligned with and directly related to state and academic content standards, student achievement standards, and assessments.
3. It improves and increases teachers' knowledge of the subjects they teach.
4. It advances teachers' understanding of effective instructional strategies founded on scientifically based research.
5. It is regularly evaluated for effects on teacher effectiveness and student achievement.

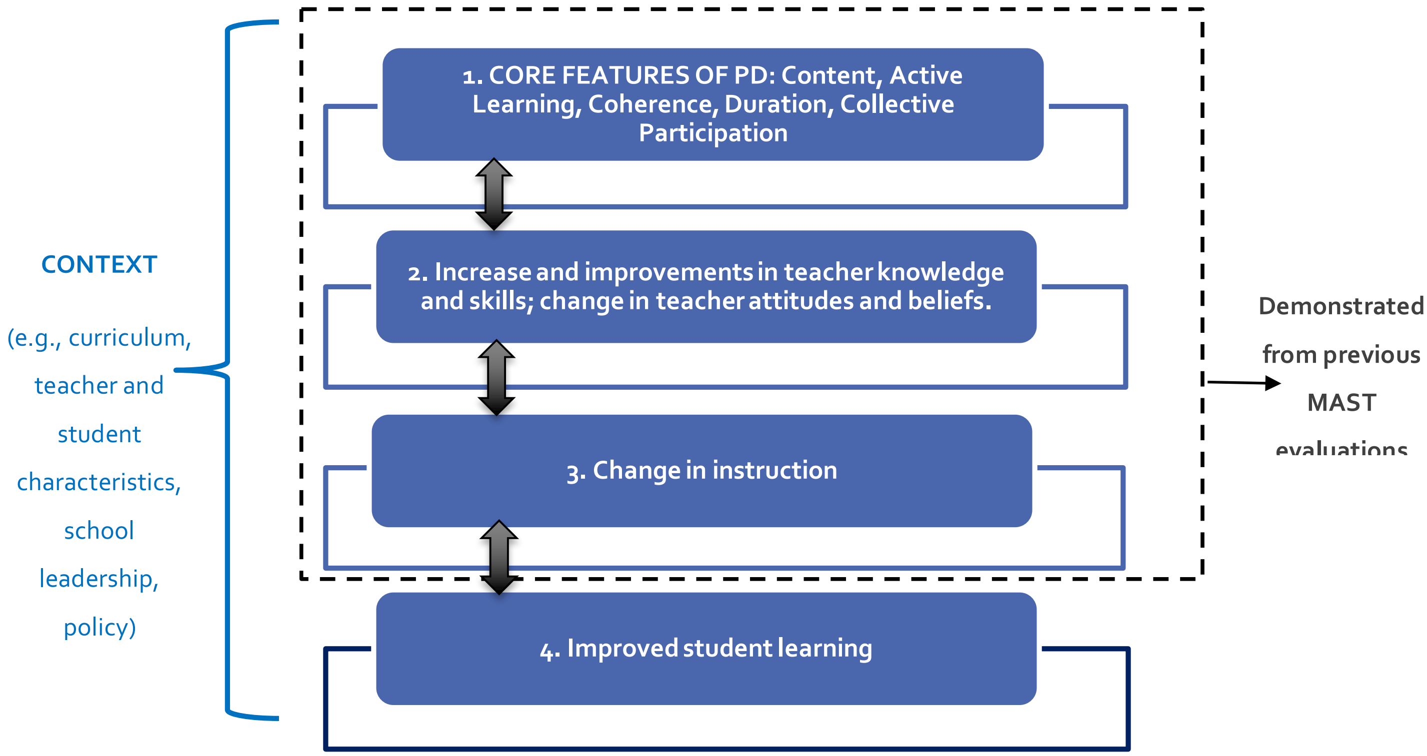
In a more expansive take on Yoon et al.'s criteria that is more evidence-based, Desimone (2009) provides a comprehensive framework for how to best evaluate the effect of PD, and the most effective components that all PD programs should encompass. This approach has been supported by both theoretical literature and empirical studies. Desimone's model (2009) points to three main characteristics of PD evaluations that can better link teachers' and students' outcomes:

- Core features of effective PD are content focused, active learning, coherence, duration and collective participation;
- Examination of these core features should include the way that the PD affects a teacher's knowledge, teaching practices, and student learning; and
- Contextual factors such as teacher, student, and school characteristics are correlated to the effectiveness of the PD.

Based on the review of literature, there are a few main ideas about "quality" PD that we found to be universally accepted. First, PD should be viewed as an ongoing process, and is most effective when it is extended beyond just a few days. Second, PD is most effective when it is designed with the specific goal of improving student achievement and learning. Third, the context of the learners and the environment must be considered. Lastly, it entails "instruction that enables a wide range of students to learn" (Darling-Hammond, 2012). While many models of PD have been proposed (Joyce and Showers, 1988; Desimone, 2009; Bell and Gilbert, 1996; Supovitz and Turner, 2000), we would like to situate the current MAST study and evaluation within Desimone's (2009) conceptual framework (Figure 2).

Figure 2.

Desimone's (2009) Conceptual Framework for PD - Modified from Desimone (2009)



The strength in Desimone's (2009) model is that it is a broad, macro-level view of PD that encompasses all the core features that have been illustrated above, and is, yet, applicable. This model encompasses all the core features of quality training that are most relevant to teachers and their students, including, "…interactive, non-recursive relationships between the critical features of professional development." The theory of action proposed by Desimone (2009) is outlined in Figure 2, which illustrates four attributes: (1) the PD should be content focused and incorporate active learning, coherence, duration, and collective participation; (2) the PD should increase teachers' knowledge, skills, attitudes, and beliefs; (3) teachers should use their new knowledge, skills, attitudes, and beliefs to improve their teaching and/or their approach to teaching; and (4) the instructional changes will improve student learning.

The MAST PD model, intervention, and theory of change include all the critical components of Desimone's (2009) model (Table 1), including the context of the PD and participants (e.g., teacher and student characteristics, school leadership, policy and reform initiatives). The previously discussed characteristics are aligned with many models that are consistent with effective science PD program and opportunities for science teachers (Supovitz and Turner, 2000; Duschl et al., 2007; Loucks-Horsley et al., 1998, Heller, Daehler, Wong, Shinohara, and Miratrix, 2012).

Table 3.

MAST's PD model aligned with Desimone's (2009) Conceptual Framework for PD

Desimone's Conceptual Framework – Critical components of PD	Core elements of MAST's PD Model
➢ Content focus	- Focus on physical science (chemistry, and physics), earth science, and astronomy
➢ Active Learning	- Inquiry-based activities and hands-on learning
➢ Coherence	- Alignment with the 2010 Mississippi Science Framework
➢ Duration	- 3 Weeks of Summer PD, with follow-up courses in the fall and spring, and on-going support and visits from MAST staff
➢ Collective participation	- Includes collaborative learning and instruction that is student focused

Summer professional development programs are the most commonly implemented type of "standardized PD" for in-service teachers; they utilize training sessions, the "workshop" model, conferences, and the "cascade" (or Train-the-Trainer) model (Gaible and Burns, 2005). The MAST program differs from such standard models in that it consists of a combination of pedagogical and content-based summer workshops, in addition to workshops offered during the school year, in-school workshops, and year-round MAST staff support and school-visits. The MAST model was developed and implemented based on current findings on effective PD, but also to emphasize strengthening Mississippi state science teachers' understanding of state-level science content standards, as well as, starting in 2010, Next Generation Science Standards. In addition, the MAST model provides participating teachers with ample opportunities for reflection and feedback in order to shape the content and quality of their PD experience.

Not only was the MAST program specifically designed using key findings and strategies suggested in the science education literature, it was also designed using lessons learned, and direct feedback from MAST participants. It is important to mention that several other PD models have similar frameworks with regard to characteristics, objectives and goals, such as: (a) opportunities for teachers to learn in similar settings as their students (Loucks-Horsley et al., 1998); (b) continuous assessment and reflection of the PD; (c) strong content focus (Desimone, 2009; Sickel and Friedrichsen, 2013); (d) inquiry-based instruction (Desantis, 2009); and e) pedagogical content knowledge. To better identify which specific elements of professional learning opportunities can promote teacher change in the science domain over the long-term, however, further empirical evidence is needed.

Many studies have examined the effects of science PD on teachers' content knowledge. Examining whether these positive attitudes and their strong impact are maintained over time can be critical in determining how future PD programs, such as MAST, should be implemented. In addition, exploring the impact of follow-up feedback, coursework, and support can help inform a more refined MAST PD model and, ultimately, program development model.

Overview of Research Design & Methods

Design

For seven out of eight evaluations, REA employed both quantitative and qualitative methods. The goals of this design were to provide formative evaluation information to highlight outcomes and areas of potential improvement, and yield evidence of the impact of the MAST program on teachers and students.

In 2016, we employed a randomized controlled trial that we are implementing in two rounds, between June 2015 and May 2017. High school science teachers who were accepted into the program were placed into one of three cohorts: a) MAST alums who began in 2015 (experimental group); b) a new cohort who began in 2015 (experimental group); and c) a new cohort who began in 2016 (control group). In 2015, teachers accepted to the program were randomly assigned to either the experimental group or control group. If they were assigned to the control group, they did not begin the MAST PD until summer of 2016. With this group, we still collected data from them and their students in during the 2015-2016 academic year, on science content knowledge and efficacy. Hence, for the control group, we have two years of data: a) one year prior to being exposed to MAST (2015-2016), and b) one year after being exposed to MAST (2016-2017). The experimental group began their PD in the summer of 2015. It is important to note that, although teachers assigned to the control group were not allowed to participate in the PD courses, they were not restricted from participating in other PD programs.

The first round of the randomized trial started the summer of 2015, which means that the control group sample completed all surveys and science tests, but did not participate in the PD. The second period of data collection began during the summer of 2016, which means that the control group participated in the PD, with their outcomes to be compared pre and post-program during the 2016-2017 academic year.

Participant Characteristics

Between 2009-2017, our eight MAST evaluations have included a total of 348 in-service teachers:

- 2009-2010 (31) – Year 1
- 2010-2011 (30) – Year 2
- 2011-2012 (51) – Year 3
- 2012-2013 (59) – Year 4
- 2013-2014 (61) – Year 5
- 2014-2015 (78)* - Year 6
- 2015-2016 (59) – Year 7
- 2016-2017 (57) – Year 8

**2014-2015 Alum Study included 78 past participants – an unduplicated number.*

Our samples each year consisted of teachers who completed surveys at three intervals: pre-workshop (T1), post-workshop (T2) and end-of school year surveys (T3). On average, each survey completion number decreased by an average of three participants at each data collection interval. In aggregate, the teacher sample was 84% female and 16% male. Forty-four percent of participants identified as African American, 35% as White or Caucasian, 7% as Asian, and 14% as Other. Fifty-three percent had an undergraduate major in biology while 15% had an undergraduate major in chemistry. In aggregate, 81% percent of participants reported earning a graduate degree in a science subject. On average, teachers had about 9 years of teaching experience overall and, on average, about 7 years of experience teaching science. Participating teachers administered surveys and content tests to their students. In aggregate, between 2008-2017, the student sample included roughly 7,800 students. Fifty-nine percent of the students were female; 76% identified as African-American.

Each year, evaluators partnered with program managers to support the program application process, recruitment, and engaged in ongoing communications about data collection. For the Alum Study, evaluators worked closely with MAST program managers to recruit alums from either the MAST I, MAST II, MAST III, MAST4U, MAST5 or the MAST program, all of which followed near identical formats for each cohort. The Alum Study served as the one instance for which evaluators oversaw all teacher recruitment. In 2014 we emailed a total of 707[4] alums that taught elementary (N=155), middle (N=266), and high school (N=278) to request their participation in this follow-up study. Of the 278 alums total who taught high school, 78

[4] Included in this total are also 8 K-12 teachers whose students change throughout the year; they teach special needs students.

completed a follow-up survey, a 28% response rate of high school teacher alumni. [5] For each study, we included data from an average of 35 teachers, who taught high school science the prior academic year before participating in MAST summer workshops.

Instruments

We administered pre and post surveys and content tests to teachers and students to measure cognitive and affective changes. Teacher surveys included questions about professional background, as well as items about teaching attitudes and practices taken from the Science Teacher Efficacy Beliefs Instrument (STEBI) (Riggs and Enochs, 1990). The post survey also asked how teachers were using the materials they received. Student surveys included items about academic efficacy and control of learning from the Motivated Strategies for Learning Questionnaire (MSLQ); self-efficacy for learning and performance and control of learning (Pintrich, Smith, Garcia & Mc Keachie, 1991).

Between 2009-2014, evaluators measured teachers' science content knowledge with the MOSART test (Misconceptions-oriented Standards-based Assessment Resources for Teachers) (Sadler, Coyle, Cook-Smith, & Miller, 2007; Sadler, Sonnert, Coyle, Cook-Smith, & Miller, 2013). MOSART is a standardized, validated, multiple-choice measure of physical science content knowledge developed with funding from the National Science Foundation's Math Science Partnership program. The test is designed to "probe for any conceptual shift(s) as a result of professional development activities, course work or other intervention" (Sadler et al., 2007) by requiring respondents to make "a choice between accepted scientific concepts and misconceptions that have been well documented in the science education literature (Sadler, 1998; Schoon, 1988; Treagust, 1986)" (Sadler et al., 2013, p. 1021). During this time, we had originally intended to give teachers the content tests that corresponded to the grade they were expected to teach in the upcoming school year (e.g., high school level) and then give students the same test version. Concerns about the difficulty of the test led us to assign middle school tests (grades 6-8) to high school teachers. In the first two years of the project, teachers took the MOSART tests twice, at the beginning (pre-program or "pre") and end of the summer workshop (post-program test I or "post I"). In the third year of MAST, teachers also took tests at the end of the fall/winter workshop series to measure retention of knowledge (post-program test II or "post II").

Concerns about the difficulty of the MOSART tests continued, and the developers of the instrument decided to discontinue administration of these instruments. Hence, evaluators decided to measure teacher content knowledge learning gains using internally developed, multiple-choice tests of science content knowledge in the physical sciences. These tests were developed by the PD instructors based on what science Big Ideas were taught during the summer courses. Student content knowledge was measured using chemistry and physics content tests comprised of multiple-choice items taken from PD content knowledge assessments - these assessments were also created by the PD workshop instructors. The content tests were used in an effort to align what teachers were taught, and assessed on, during the PD. Additional details about the instruments, including sample items and scale reliabilities, appear later in the sections of evaluation.

Alum Interviews

Each interview lasted approximately one hour, and was both recorded and transcribed. The interviews centered on how teachers perceived their own professional changes due to their participation in MAST, including formative feedback on the program years after completing the program. For instance, the interview assessed teachers' perceptions of how and why he or she had changed since the MAST program ended and, if so, how they changed.

We analyzed all interview data using the Grounded Theory method, a systematic methodology in the social sciences involving the discovery of theory through the analysis of non-numerical data (Strauss & Corbin, 1990). In employing the Grounded Theory approach to the analysis, evaluators: (a) simultaneously collected and analyzed all qualitative data and transcriptions; (b) created analytic codes and categories developed solely from the data; (c) discovered basic social processes within the data; (d) performed inductive constructions of any abstract categories; and (e) integrated all categories into a theoretical framework. The Grounded Theory method has become the paradigm of choice for qualitative research and analysis, in that it provides a set of procedures and a means of generating a theory that is reflective of the data. This particular method of research and analysis provided insights to help guide the formation of theoretically relevant implications for future research.

How is MAST Implemented? MAST in Action

A Day of PD Sessions

As stated, MAST implements its objectives by engaging teachers in four weeks of graduate coursework on content and pedagogy in science (three weeks in the summer, five Saturdays during the school year). During these classes, teachers learn physical, earth, and space science through a combination of lectures and high-school level hands-on activities. While MAST programming has focused on the Mississippi Curriculum Framework objectives (aka, MAST "Big Ideas"), the instructors and sessions have varied slightly every year based on the needs and interests of the participants. Evaluators observed the session annually, and most observation data remained consistent. The following is an observation from the summer of 2016, describing a few MAST lessons designed and executed by PD instructors to illustrate ways in which teachers can use various teaching strategies and science content from the Mississippi State Science Standards in their classrooms.

Evaluators observed two days of sessions to learn about the impact of the PD in real time, how teachers interact with one another and with staff of both the new cohort of teachers and the alumni group, as well as ways in which PD instructors executed their lessons for the teachers. All PD courses were designed to help prepare teachers for the classroom, offering instruction, suggestions, and strategies on: inquiry-based science teaching, classroom and materials management, equitable teaching strategies, cognitive development, and lesson planning. Observations took place in June during the second week of the professional development series for the new cohort and during the physics sessions for the alumni. Observations of the new cohort included a morning session on earth and space science and one session on physics covering the topics of work, power, and energy; the alumni observations occurred during two afternoons covering the topics of Arecibo's Giant Mirror and Diffraction of Light.

New Cohort, Day 1:

The instructor started out the morning stating we are going to have an "inquiry intense day." The goal of the session was not to give an excess amount of information, but to help teachers learn through exploration. With this one full day workshop teachers started the morning looking at pictures of the earth, which lead to a discussion about the differences in observations and inferences in science based on images that were familiar to teachers and students. Once teachers had a sense of observations and inferences, the instructor showed images taken from outer space, including the first images of the moon, comets, etc. Using their knowledge of observations and inferences, teachers were asked to complete an activity. They were given a group of cards and asked to create groupings or categories of solar system objects based on pictures and descriptions found on the cards. The instructor moved the activity along by pausing the teachers when necessary, engaging in discussions, and adding more cards to be categorized.

During the activity, some teachers were engaged in conversations with one another in small groups, while others took notes. When talking with the new cohort teachers during breaks, a few indicated that earth and space science, specifically astronomy, is not taught at the high school level, but rather at the middle school level in Mississippi. Even though the content of the session may not have been relevant to the majority of teachers, they did find value in talking about the difference between observations and inferences, which are part of the Mississippi State Science Standards. To wrap up the session, the instructor discussed ways teachers could use this activity in their classrooms. One example was using a method of categorizing when teaching taxonomy systems. The instructor noted, "when you discover new things, categories can change." At the conclusion of the session, teachers expressed the need for more examples of how they could take the activity back to their classrooms and use it in many different contexts.

New Cohort, Day 2:

The new cohort of teachers started day two with new PD instructors, discussing the topics of work, power, and energy in physics; this was the first day of a two-day series. During the previous week, teachers worked with and were given a Labquest (Vernier), pH sensor, along with other technology gadgets. This workshop continued to build on their knowledge of how to use the technology tools in their classrooms. The instructors also gave them alternative low-cost ways to implement the lessons when the technology is not available. Since the technology was new to the majority of teachers the instructor reminded teachers about the importance of setting aside extra time for planning and delivery of instruction in case there is a problem with the technology, the instructor stated, "the first time through, plan on double the amount of planning time due to the technology."

The session was filled with teaching strategies that could be used across all areas of science and also covered some physics content included in the Mississippi State Science Standards. Teachers started out creating a glossary book. The instructor then reminded teachers to think about how they will use these activities in their classroom. One teacher shared, "In my earth science class I used a lot of Foldables [graphic organizer] and the last 5 minutes I would let them use their Foldable on the test. This taught the students to use resources and tools, but not allowing it to be a 'crutch'." Other strategies included classroom management techniques, such as how to make sure everyone is listening, how to increase student's writing skills through reading out loud, using thumbs up and thumbs down as a quick way to gauge the level of understanding, and a parking lot for unanswered questions. Throughout the morning session, the instructors and teachers went through six vocabulary words with an activity for each that highlighted how the word is used in the context of physics. This activity allowed teachers to solve problems using equations.

Alumni Cohort, Days 1 and 2:

The first two days of the three-day physics workshop for alumni, PD instructors and teachers worked through activities provided by the CNS Institute for Physics Teachers. Instructors gave teachers background information needed to start each of the activities through lecture and PowerPoint slides. Teachers worked on one activity at a time answering guided questions in small groups. At the conclusion of each activity, instructors wrapped up each activity with a short debrief that was mostly instructor lead.

During both days of the observed sessions, instructors gave teachers plenty of time to work through each activity. Teachers and instructors talked about how the physics content in the activities could be inserted into lessons for biology and chemistry, since not all the teachers in this session were physics teachers. The second day of the workshop gave teachers a chance to do inquiry work with a light bulb activity. Teachers came up with a list of variables they might want to explore with the light bulbs and were tasked with creating a consumer report to showcase their findings. One group of teachers talked about how this was a new activity they had never thought about doing with their students.

Teachers appreciated that through their participation with the MAST program they were walking away with lab activities they could implement in their classroom. The MAST sessions also provided teachers with the necessary training to check out materials in the lending library through Cornell University and Jackson State University. These materials are only available for the activities completed at the sessions, and a few alumni shared that they have used the lending library in the past.

MAST Behind the Scenes:

An essential element in MAST's often seamless implementation is fueled by the program administrators in the Department of Physics, Atmospheric Sciences & Geoscience (PASG). The team of MAST administrators have been in charge of direct communication with participants, scheduling the PD sessions, managing stipends earned by participating teachers, and program budgeting and accounting. The administrative team underwent very little turnover between 2009-2017, fostering more refined program planning and execution year after year. The same administration team has also worked on three additional JSU PD programs in the same Department: MAST 5, MAT-PD (Mathematical Advancement Through Professional Development) and ICFAIM (Institutional Change through Faculty Advancement in Instruction and Mentoring).

During MAST's PD over the years, teachers showed signs of engagement in the workshops; teachers willingly answered questions, talked with their peers, and took notes. The sessions described above included several elements covered in the PD, such as: general classroom strategies to use for effective lesson implementation, classroom management strategies, use of hands-on activities for teachers to learn so that they can use them in the classroom with their students, use of small groups, and strategies for engaging students. The implications of this narrative are that teachers seemed to appreciate the variation in how the workshops were presented; each instructor had a different style with how they delivered information to teachers. While it is not possible to assert that the narratives described above would transfer to other teachers' experiences, or other contexts, care must be taken to ensure that elements from the MAST professional development are practical in a wide range of contexts, particularly in terms of measuring participants' outcomes.

Accomplishments and Key Outcomes (2009-2017)

This section serves as on overview of long-term findings, using several data sources to describe the implementation and impact of the MAST program and some of its key benefits for teachers and students over the years. We first start with our list of benchmarks and goals. We then move to teacher findings (overview of MAST implementation analysis and teacher impact) in Section A, followed by and overview of changes in teacher practice (Section B). Section C reports on student findings. Each section ends with conclusions. Our report concludes with a summary of findings, lessons learned and final discussion.

The following table reports the outcomes and benchmarks from the fourth Project MAST cohort, June 2012-March 2013. Data is currently being collected for the fifth (final) cohort and will be reported in the 2014 cumulative report.

Table 4. MAST Goal Matrix

Goals: a) Improve teacher quality and efficacy in high school physics, physical, earth, and space science classrooms, b) Improve teacher science content knowledge, c) Improve student efficacy for learning science and interest in science, and d) Improve student science content knowledge.								
(a)	(b)	(c)	(d)					(e)
Objective	Benchmark/ Indicator	MSP Key Feature	Level of Attainment (check one)					Brief explanation for changes, new benchmarks, and target dates
			Benchmark met	Benchmark not met	Target year has been revised	Benchmark has been revised	No longer a project benchmark	
Increased teacher knowledge in physical and space science	Greater gains from pre to post in teacher content knowledge	2, 3, 4	√			X		Benchmark has been changed to “Statistically significant gains from pre to post in teacher content knowledge.” Control group has been eliminated due to the difficulty recruiting comparable participants.
	Change in perceptions of knowledge	2, 3, 4	√					Supporting evidence can be found in this section.
Increased science teaching	Greater gains from pre to post in science teacher efficacy `	2, 3, 4	√		X			Benchmark has been changed to “Statistically significant gains from pre to post in science teacher efficacy.” Control group has been *included* during Year 7 & 8.

and learning efficacy	Self-reported gains in efficacy for teachers	2, 3, 4	√					Supporting evidence can be found in this section.
Improvement in teacher practice: science content enactment	Teachers demonstrate enactment, defined as: Use of MAST-like materials as opposed to materials used previously	2, 3, 4	√					Supporting evidence can be found in this section.
	Use of MAST pedagogical strategies (e.g., inquiry) as opposed to strategies used previously	2, 3, 4	√					Supporting evidence can be found in this section.
	Use of MAST learning goals as opposed to learning goals used previously	2, 3, 4	√					Supporting evidence can be found in this section.
Improvement in practice: science technology integration	Use of MAST technology materials as opposed to technology used previously	2, 3, 4	√		X			Target year has been revised. Additional information on baseline technology practice must be collected.

Improvement in practice: adaptations of curricula	Use of MAST adaptation strategies in teaching the same content in which the strategy was modeled.	2, 3, 4	√		X			Target year has been revised pending further study of the implementation of the curriculum adaptation component of the program.
	Use of MAST adaptation strategies in teaching different content in which the strategy was modeled.	2, 3, 4			X			Target year has been revised pending further study of the implementation of the curriculum adaptation component of the program.
Increased science student learning efficacy	Greater gains from pre/post in student efficacy	3, 4	√			X		Benchmark has been changed to “Statistically significant gains from pre to post in student efficacy.” Control group has been included during Year 7 & 8.
	Self-reported gains in efficacy for students	3, 4	√					
Increased student content knowledge in physical and space science	Greater gains from pre to post in student content knowledge and attitudes towards science	3, 4	√			X		Supporting evidence can be found in this section. Benchmark has been met; students improved their performance on the MOSART physical science content tests minimally. Students increased their science content scores significantly once new test was adopted.

Increased knowledge of the MAST program by school administrators	Gains in perceived knowledge	1, 5				X		Administrator seminar was not held between 2014-2017.
	Gains in perceived appreciation	1, 5						
	Gains in perceived support by participating teachers	1, 5		X				
Attitudinal change among university faculty towards teaching science.	Gains in perceived importance of teaching science to (a) increase undergraduate content knowledge and (b) prepare student teachers	1, 5		X				
	Adoption of strategies modeled by other instructors in workshops	1, 5			X			

A. Teacher Findings

(I) Long-term Impact of MAST

In 2015, we emailed a total of 827 alums teaching elementary, middle, and high school, and 241 participants completed the online survey. We only included the data of teachers who taught high school at the time of MAST (the most recent iteration of the programs). Of the 241 high school teachers in the five cohorts, 78 were included in this study. All but two of the past participants in this study still work in the field of education (93%) and are still teaching. The majority of teachers were female (83%) and more than half of the teachers (69%) identified as African American. All teachers were certified, and 54 held master's degrees. The teachers' years of experience in the classroom ranged from four to 45 years.

Survey Findings

Former MAST participants completed an online survey in which they estimated the extent to which they feel their knowledge and skills have been enhanced in the following ways as a result of participating in the program: (a) instructional methods, (b) deepening knowledge of science, (c) use of technology in instruction, (d) adapting teaching to meet Mississippi State Standards or the curriculum framework requirements, (e) adapting to meet Mississippi State assessment requirements, and (f) strategies for teaching diverse learners.

As seen in Figure 3, using a 6-point scale with 6 being "to a great extent," former participants reported deepening knowledge of science (M=4.65), use of technology in instruction (M=4.42), and instructional methods (M=4.33) as being enhanced the most. Strategies for teaching diverse learners were the most infrequently cited (M=3.91). When asked about changes in their teaching practices as a result of MAST, using a 6-point scale with 6 being "to a great extent," three changes in practice rated well above 5 points: (a) use of technology in instruction (M=5.25), (b) the cognitive challenge of science activities (M=5.24), and the instructional methods employed (5.23) (Figure 4).

Figure 3.

Changes in Knowledge and Skills (Mean Ratings): To what extent do you feel that your knowledge and skills have been enhanced in each of the following areas? – Mean Ratings (N=76)

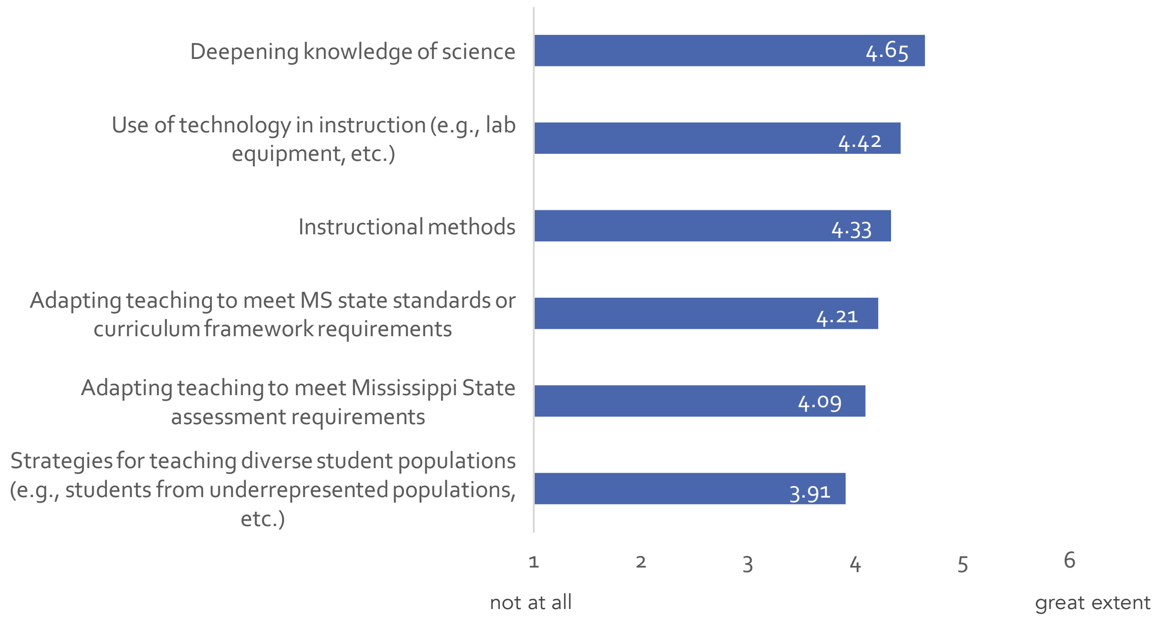
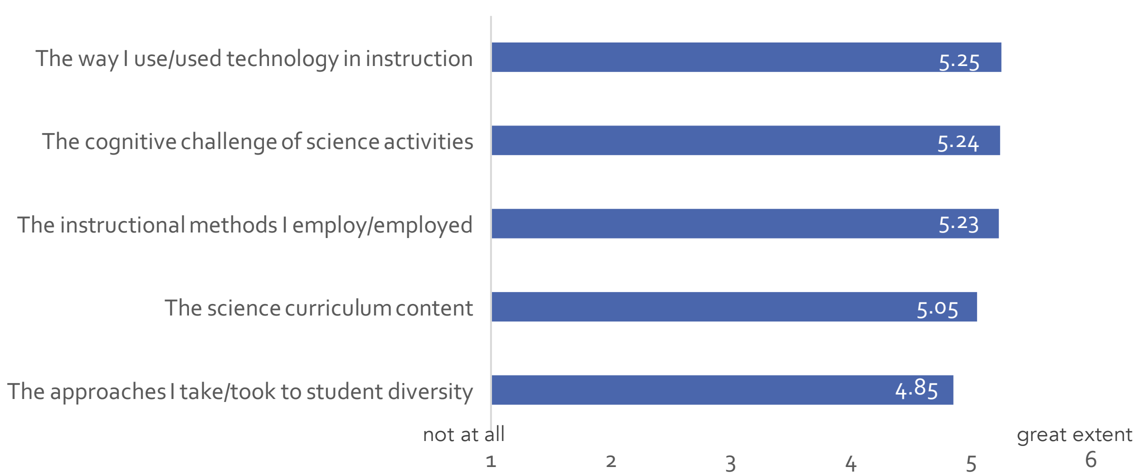


Figure 4. Changes in Teaching Practices (Mean Ratings): To what extent have you made changes in your teaching practices as a result of MAST? – Mean Ratings (N=75)



Past MAST participants were asked a series of questions related to the expansion of their community of practice since graduating from the MAST program. As shown in Figures 5 and 6, engaging in more self-directed learning (e.g., discussion with colleague about science or science education topics, read a journal article on science or science education, use the internet to enrich knowledge and skills) (M=4.65) was the most frequently cited professional activity teachers participated in since graduating from the MAST program. An increase in self-directed learning was followed by: (a) acting as a coach or mentor to other teachers and staff at their respective school (M=3.59), and (b) participated in a teacher network or collaborative or teachers supporting professional development (M=3.35). After participating in MAST, 34% of teachers reported giving presentations at conferences related to science or science curriculum following their participation in MAST (34%) (Figure 7). Of this group, the frequency of teacher presentations prior to and after MAST remained unchanged (Figure 8).

Figure 5. Expansion of Community of Practice (Total Frequencies): Between the time you participated in MAST and now, how frequent have you engaged in each of the following activities? (N=75)

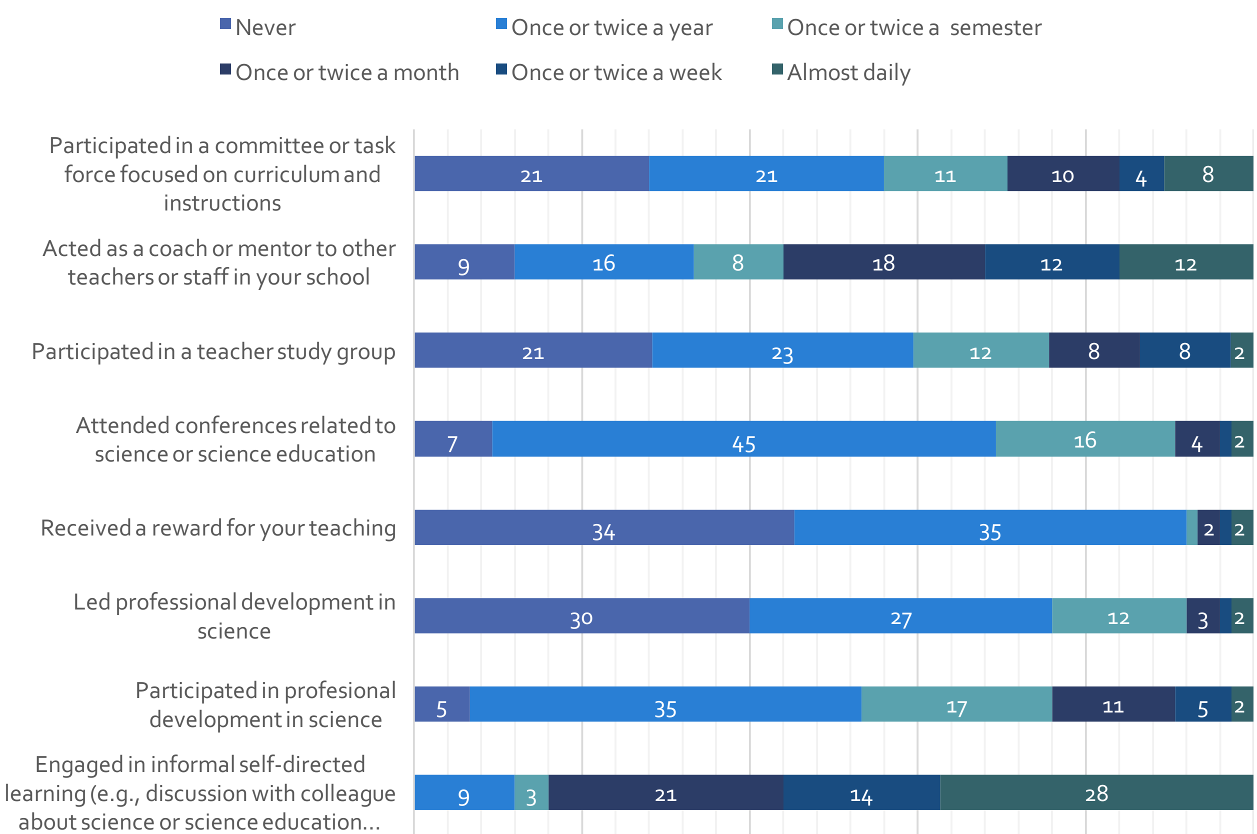
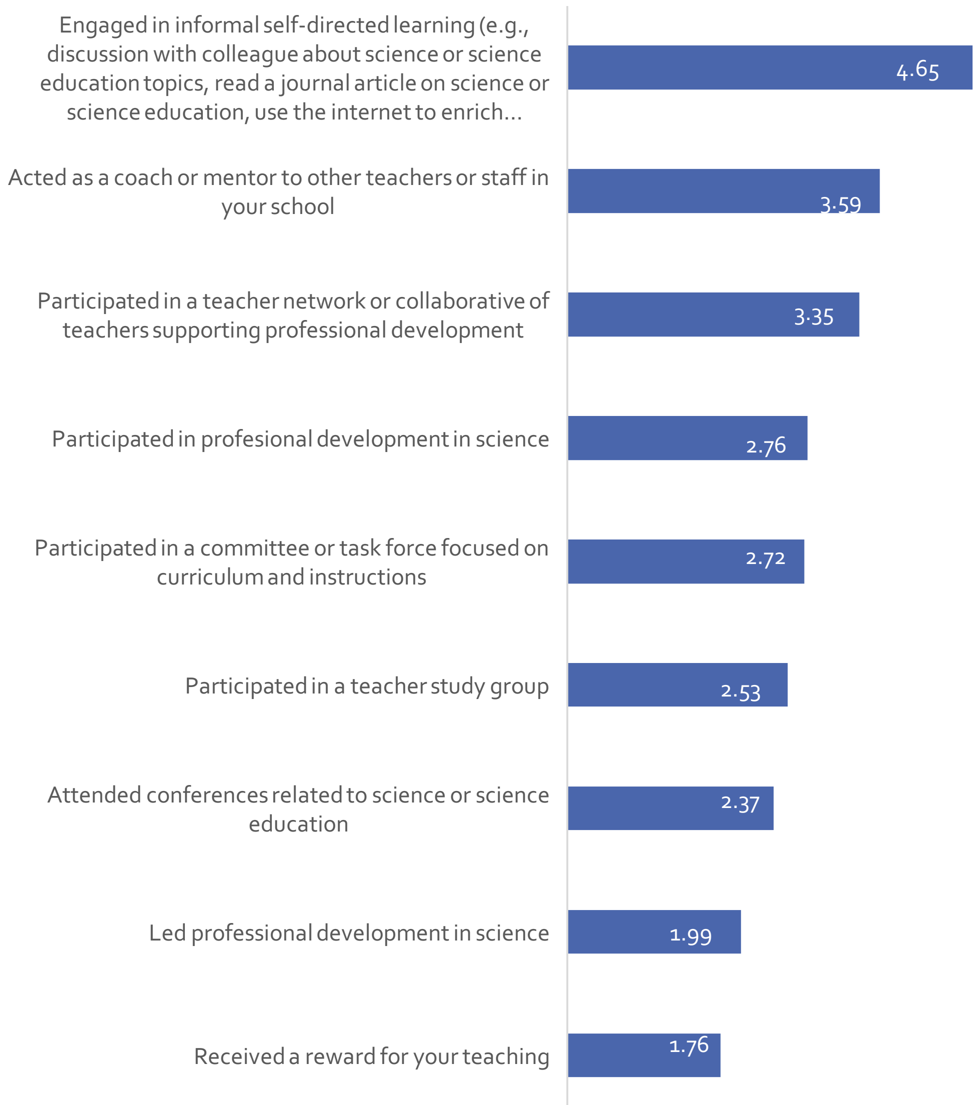


Figure 6. Expansion of Community of Practice (Mean Ratings): Between the time you participated in MAST and now, how frequently have you engaged in each of the following activities compared to before MAST? (N=75)



1=Never, 2=Once or twice a year, 3=once or twice a semester, 4=Once or twice a month, 5=Once or twice a week, 6=Almost daily

Conference Attendance

Figure 7.
Have you given presentations at conferences related to science or science curriculum since MAST? (N=76)

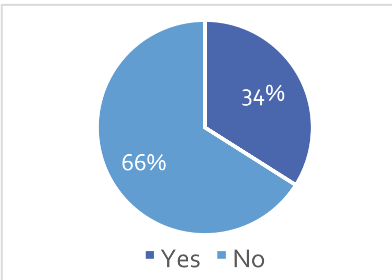
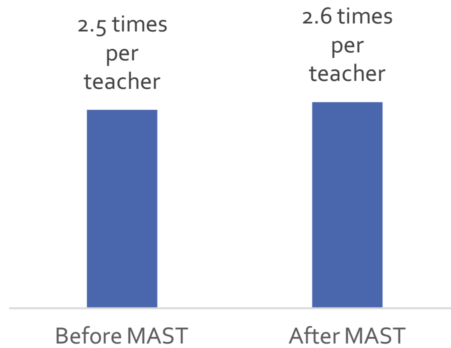


Figure 8.
How many times have you given presentations prior to and since attending MAST? (Average) (N=26)



Based on the survey data alone, MAST appears to have had a moderate impact on teachers' self-reported content knowledge and skills over the long-term. With regard to changes in their teaching practices, the long-term impact appeared to be much greater, with scores of 5 out of a 6-point Likert scale ("to a fairly great extent"). In years prior, high school teachers had the opportunity to learn science through inquiry in the summer and fall workshops and then bring those same lessons and materials back to their students. That nearly all teachers reported fairly moderate changes in their content knowledge and skills based on what they had learned in MAST, and considerable changes to their teaching practice, are indicators of the program's sustained relevance, practicality and sensitivity to teacher needs. After attending MAST PD, it appears that teachers have expanded their community of practice (a considerable amount) by engaging in self-directed learning of science (M=4.65).

While teachers reported these changes up to 7 years after attending the PD, it would be important to look at the pre and post outcomes of this particular group when they first started in the program (as early as 2008), and compare these short-term gains (or losses) to the same pre-post measure today. A selected group of past participants returned to MAST and participated in PD during the summer of 2015. Using the same outcome measures we used in our prior evaluations (Science Teacher Efficacy Beliefs Instrument (STEBI), Patterns of Adaptive Learning Survey (PALS)), we will be able to compare scores from before their initial participation in MAST to after completing the second iteration in the spring of 2016. Reporting pre and post efficacy and adaptive learning scores together may suggest that the MAST PD model may be (at least to some extent) instilling and maintaining, long-term change in teachers' content knowledge, skills, and pedagogy.

Interview Findings

The second section of this report will summarize findings from 20 individual, hour-long interviews with teachers who graduated from MAST between 2 and 7 years ago. These teachers spoke candidly about how the MAST program impacted their beliefs and practices years after the PD. Teachers were asked questions about the following topics:

- Professional changes since attending MAST
- Perceived student benefit to teacher PD
- Application of the PD to teaching (short and long-term)
- Expansion of teachers' community of practice
- Additional long-term impacts

"MAST has overall made me a better teacher. I include more activities and NGSS standards into my lessons. I also am a lot more confident with my teaching in the classroom and with taking risks. MAST gave me so many new ideas in the classroom and has made me more open to feedback and thinking critically about what activities and steps in the lesson make the most sense. Student engagement is up with the hands on activities that I learned about during

Professional changes since attending MAST

There was no shortage of feedback from past participants about some of the lasting impacts of MAST. Teachers discussed some of the professional changes they have made as a result of participating in MAST. Three-quarters of the teachers interviewed (15) discussed how the program changed their approach to teaching science. Two teachers commented on the benefits of adopting new perspectives and introducing new materials; one teacher spoke of this as a result of having more confidence:

> *I was able to present concepts in a new way to my students. And you know after you taught something for so long you kind of go back to the same material. It was nice to have a new perspective and new layouts and sometimes new equipment to try to change things up a bit. (2011-2012 MAST participant)*

> *I've gained some confidence in myself in understanding that I'm not too old to learn. I'm not too old to change…I can still adapt. I can still change. I can still improve and make it better for my kids. (2009-2010 MAST participant)*

Several teachers spoke about using more hands-on activities and inquiry as a result of MAST, and implementing what they learned from the program, as a way to keep students actively engaged and involved:

> *The fact that I teach science, of course, we do labs and experiments and things. But I think one of the most significant things that I started doing after I left MAST was just doing, not necessarily labs, but just more hands-on activities. Smaller hands-on activities to get my students excited about learning science. (2011-2012 MAST participant)*

> *I definitely use more hands on things. I used the book less and at least the students have to use the book less because now we're doing science more than just reading it and answering questions. We're experiencing things and they enjoy it more. (2010-2011 MAST participant)*

> *Basically, trying to use more of a flipped classroom model. And I know they didn't really focus on that, but as being a participant, I saw the benefits of giving students instruction and then when I'm with them, having them do hands-on things themselves...I try to do more of getting the students actively involved, instead of me doing all of the talking. And inquiring, questioning techniques that get them thinking. (2009-2010 MAST participant)*

Moving away from teacher-centered learning and more towards student-centered instruction and inquiry was frequently mentioned as a distinct shift in their approach to teaching. Some teachers seemed to struggle with the idea that teaching is more than just delivering content, that it involves adapting strategies and techniques that promote student learning. The following two teachers discussed the transition from lecture-style teaching to inquiry-based learning as a result of MAST:

> *I have learned through Project MAST it's not about the teacher imparting knowledge as the great guru, it is letting students experience, letting students have the opportunity to put their hands on materials, helping them to develop the right ideas. It's more guided. The teacher should be the facilitator and not the be-all, end-all guru. I've had to learn not to do that. (2006-2007 MAST participant)*

> *A lot of the focus on MAST was that inquiry-based learning, where it's not so teacher-centered, it's more student-centered learning. So it took me from, basically, just telling the kids stuff and then giving them an assignment afterwards, to just letting me give them an activity to learn themselves, and then kind of guide. It really helped me understand how to do inquiry-based learning. (2008-2009 MAST participant)*

Teachers reflected on improving their science content knowledge, and drew parallels to how having a better understanding of the science content benefits their students. The following teacher reiterated this point, and also mentioned how MAST sparked her interest in science subjects, particularly electrical models:

> *I incorporate more physics principles into my classes and this has helped me add more STEM activities, labs and projects to my courses. It also helped me understand the subject so that my students can understand it better. If I don't know something, how can I effectively teach it? Recently I ran across an old issue of a physiology education journal. While flipping through it I noticed a nervous system model of a reflex arc without pain and one with pain associated with it. The models were built using electrical switches, lights, buzzers, wires and motors. Before MAST I would have skipped over this information but because of MAST and the week of half-day workshops on electricity I am now incorporating the models into both of my AP classes and my AP Biology class. I have purchased all of the electrical parts, made kits for groups of 4, and am teaching neural circuits with my electrical models. My students and I are getting a much clearer understanding of sensory neurons, interneurons, motor neurons, the spinal cord, ascending and descending tracts, and the flow of information within the nervous system. (2008-2009 MAST participant)*

Two teachers discussed how their understanding of the science subject matter increased their confidence, which, in turn, likely benefited their students:

> *Building confidence on some of the content, and being able to break down material for kids that I didn't fully understand prior to the MAST program. (2008-2009 MAST participant)*

> *With teaching the upper-level kids, I have more confidence. For example, I teach marine biology, which I told you, and we had a lot of earth concepts. After going to MAST and learning earth science and chemistry, I have a better way of communicating that with my kids and have a more thorough understanding of it and appreciation for the subject. (2011-2012 MAST participant)*

Several teachers reflected on their time before participating in MAST, and that because of the program, they now encourage their students to meet higher expectations. One teacher summed up this point with the following comment:

> *I expect more from the students. I expect them to have more higher-level thinking. I expect them to be able to do more physical content. I think my expectations of my students before I went to MAST was too low, and so we've kicked it up a notch, definitely. (2013-2014 MAST participant)*

Teachers also learned how to balance content coverage, such as how to better align the content covered in class with student assessment content:

I think sometimes I'm more reflective on how I'm going to test things at the end, to make sure that I fully covered things, to make sure that that's going to be incorporated, you know, that everything that I teach - I might over-teach the content, but I'd rather over-teach than under-teach what's going to be tested on my students. So that has helped. It made me actually think about that skill.

Finally, some teachers mentioned additional ways MAST has changed their approach to teaching over the long-term, such as different ways of teaching science with inquiry, teaching diverse learners, and classroom management techniques.

Implementation and application of PD to teaching and use of materials

At the time of the interviews, the majority of teachers (14) mentioned that they continue to implement lessons learned from MAST; 12 teachers reported implementing lessons as is, or as they were taught during the PD, and nine teachers reported adjusting the lessons to better suit their students' needs (e.g., scaling back the level of difficulty to better suit the learning curve of their students; substituting materials or not having enough materials). Below outlines the most frequently cited MAST lessons still used today, along with the number of teachers who cited each activity:

- Newton's Laws lessons (6)
- Stomp rocket activity (6)
- Vernier Software (Labquest) (5)
- Rock collection activity (5)
- Water bottle activity (4)
- Marshmallow activity (4)
- Probe activities to measure pH and temperature (3)
- iPad/iPod (3)

A teacher who participated in 2013 outlined in detail all of the materials she still uses in her classroom:

I still use so many of the MAST materials. The iPad, Vernier LabQuest, Science Formative Assessment book, MAST notebook for ideas, rock box, tuning forks, grant writing guidelines, personal white board. I got a set for my class after MAST, which I use when teaching math in physics. I start class with an agenda and clear objectives now for the day or week. I use bowling balls that I received through the MAST grant and the "thinking small" strategy and getting students to diagram what is happening on a molecular level, using science composition notebooks to record activities and data collection…the 'making claims' and 'defending your claim' in science strategy. I learned this in the chemistry portion of MAST. (2012-2013 MAST participant)

When asked why she continues to use the MAST lessons and materials, one physical science that graduated in 2010 mentioned:

> *I incorporate MAST information and ideas into my teaching throughout each year. The attributes that spoke to me were the fact that the material was new to me, easy to use, and expanded my knowledge base. (2011-2012 MAST participant)*

Eleven past participants specifically talked about the ease of implementing MAST lessons even today, and using the materials given to them back when they participated. Teachers also liked the PD activities because they were easy to plan and modify when necessary. A 2012 graduate described one example of how she modified a MAST lesson to better suit her students:

> *Well, I did that yesterday because I learned the lesson as in you do a pattern like, "Okay, this is the lesson. You're supposed to do it like this, and then go ahead and do separating this material and come up." That's the lesson I learned from there. When I taught the class, I had to modify the lesson because my students, like I said, they're special education students, so I had to utilize the instruction. So what I did was instead of writing everything what they learned from the lesson, some students I gave a bubble map. They put life on the Mars in the middle of the bubble and around that…plants or sand and water, that kind of stuff. Whereas with some other students, they just go ahead and put the things, and other children write the chart and talk about it. That kind of modifications I did. (2013-2014 MAST participant)*

Another teacher reiterated the need to make minor modifications to a lesson but, for the most part, implements the MAST materials and activities in the same way:

> *I put my own personal thinking on it and everything, but it is still - all the information was the stuff they gave us down there. And then I just tweaked it a little bit, and made it fit me.*

While past participants seem to report long-term change in many areas of their teaching, we still do not have measured outcome data (e.g., science content knowledge, teaching efficacy, etc.) to support that these changes have occurred over the long-term. Our upcoming evaluation, which is discussed in the Conclusion section, will outline our approach to capturing this information.

Perceived student benefit from the MAST coursework

The long-term impact of the MAST program on students is yet to be determined; little can be stated beyond the self-reported comments from former participants. Since we only have indirect data on student impact from 17 teachers, the generalizability of the findings is limited.

With that in mind, some clear themes emerged based on the teachers' reported student impact. First and foremost, teachers reported that their students enjoy the hands on activities from MAST over lecture-style instruction. Second, teachers recognized that MAST helped improve their science content knowledge; in their eyes, a better understanding of science content may result in a heightened understanding of the content for students. Consider the following interview responses to the question "In what ways has MAST influenced your students' knowledge, confidence, and/or learning? In what ways have you seen this?"

> *The MAST lessons are very hands on and student centered. This is what appeals to me the most. Activity based lessons drive student thinking and this allows students to explore and correct their own misconceptions. They become responsible learners. (2010-2011 MAST participant)*
>
> *They really enjoy touching something or being able to do something, opposed to just traditional sitting and listening to me lecture. (2010-2011 MAST participant)*
>
> *Being able to actually do things themselves, like design their own experiments and just being able to take control of what they're learning. (2012-2013 MAST participant)*
>
> *Lab days are their favorite days, because they actually get to interact, they actually get to touch. (2009-2010)*
>
> *The spring of the year after I had gone through MAST, we had a shift in teaching duties and I was moved into a physical science classroom. The kids had been doing worksheets all year. They had had very little instruction. So the first thing that I did when I went into that classroom was we started doing hands-on activities. We got the magnets out. We got the lenses out. We did things with our hands. They were stunned at how much more they learned by what they called playing with the magnets, participating with that, than all they had done prior to that nine weeks. So I think those that have that opportunity really do feel more confident. The principal at that time was very impressed with the fact that the kids were getting to participate. And my kids still are. I can't say they aren't. (2011-2012 MAST participant)*

On how teachers' understanding of science concepts benefits students, two teachers commented:

> *I think that they – it transcends to them, that they have more of an appreciation for it, too. It's really hard to teach stuff about the planet whenever you're such a small person on the planet to wrap your head around the scale of it. I think the fact that I have a better understanding of it, I can teach it to the kids a lot better. I definitely have a lot more confidence in those areas. (2009-2010 MAST participant)*

> *Yeah, I for sure think that they benefited after I participated in MAST 'cause, like I said, I understand the concepts a lot more in teaching those to kids. I understand chemistry a lot more so I can prepare my students for the next step that they take after being in my class, biology I. Yeah, I think that they definitely have benefited 'cause my knowledge has expanded, so therefore their knowledge will expand when I teach it to them. (2012-2013 MAST participant)*

Overall, comments from teachers suggested that the MAST program provided them with engaging hands-on lessons, which, in turn, the students reaped benefits from. Additionally, several teachers reported the importance of having a better understanding of science concepts themselves so that they are, in turn, better able to teach these concepts to their students.

Community of practice

MAST alums were asked to reflect on the ways in which the program helped them expand their community of practice. Specifically, teachers were asked:

- In what ways has MAST influenced your professional activities related to teaching (e.g., staff development, demonstration lessons, attending conferences, work groups with other teachers)
- Do you talk about your MAST experience and the use of MAST materials with others?
- Do you share the resources with others in your school or at school meetings?

All 20 of the past participants interviewed reported sharing their MAST materials and resources with other teachers, and almost all (16) alums admitted to sharing general information about the program and attending more conferences since graduating. Half of the alums interviewed reported increasing their science teaching community with more professional connections since MAST. One past participant that graduated four years ago discussed recruiting other teachers and sharing MAST materials. The participant planned on attending the Alum PD program during the summer of 2015 and spoke of other ways her community of practice has expanded:

> *After my MAST experience, I recruited 2 more of my faculty members for the following summer. They have both applied already for the alumni MAST and I will finish my application this weekend. We have MAST discussions and all 3 of us incorporate MAST principles into our teaching. One teaches physics: one chemistry, and I biology. I have distributed materials and books that I received at MAST to many of the teachers in my department, some to Lower School, some to Middle School, and some in Upper School. Many friendships were forged during MAST with teachers from around the state as well as with some in my home city. There are several that I keep in touch with and we continue to discuss professional topics related to many that we learned at MAST. I*

presented a talk at MS Science Teachers Association with one of my MAST friends. (2010-2011 MAST participant)

A more recent alum shared the same sentiment about sharing MAST materials, and attending more conferences with the hopes of improving his school's science department:

> *…I do share my materials. We've shared activities. We have encouraged people to participate in Project MAST. We've encouraged them to attend conferences because we see how valuable the networking is. So our materials have been shared. We are making a true push throughout the science department to make all of the classes in the science classrooms more interactive, giving kids more of an opportunity to get into the labs, to do inquiry, to really push towards getting outside of the book. (2013-2014 MAST participant)*

The following alum discussed how MAST inspired her to network and reach out to other teachers with the goal of increasing student engagement and interest in science at her school:

> *I am the only teacher of the physical sciences at my high school. I am reaching out to other grades and trying to partner with other teachers to get kids excited about science and about coming to high school. My hope is that this will encourage kids to stay in school and graduate and to try new and difficult subjects. Last year, we did a Sharing Science lesson with the 5th grade. My physics students taught a Newton's Law lesson to the 5th graders. I am trying to do a similar thing this year. MAST was my inspiration for reaching out this way. (2009-2010 MAST participant)*

> *I also try to get as many people to participate in the program as well. I'm recruiting all the time. This has also taught me to ask others in the community for support. I reach out to local businesses to support teachers by helping with supplies or directing them to Donor's Choose to help fund proposals.*

> *MAST has resulted in an increase in my networking with other teachers in the state. I have co-taught a science camp for the last 2 summers for underserved children in my area. The camps were project-based and my choice of projects was greatly influenced by my MAST experiences as they were all STEM projects and heavy in physics and chemistry. I have been collaborating with 2 professors from the University of Mississippi Medical Center to develop and teach two Summer Research Institutes for teachers and have hosted them at my school. The choice of some of topics/labs was influenced by MAST.*

During the individual interview, three past participants specifically referenced the National Science Teachers Association (NSTA) and how the conference and affiliation has helped expand their community of practice.

> *The NSTA Conference MAST sent me to was an eye opening experience. It let me know a wealth of opportunities to educate yourself are available. I try to incorporate a demonstration into as many lessons as possible. Suggestions from other MAST participants led me to use Edmodo in the classroom. The Edmodo Science Teacher's group has new ideas and suggestions posted daily. (2012-2013 MAST participant)*
>
> *Since MAST, I have become a standing member of NSTA and attend various conferences regularly. I try to bring as much knowledge as I can to other teachers by conducting and facilitating workshops that focus on various science content and science teaching practices. (2009-2010 MAST participant)*
>
> *I always did our Mississippi State conference that we have, but I've never been able to go. I went to a regional conference for NSTA, and I was never able to do anything like that 'cause it's just not financially possible. With them backing me up financially I was able to do that, and that was an amazing experience. If I ever have the financial backing to do it again, I would for sure do it. I always encourage my other coworkers, "If you have an ability to do it, do it, because it'll definitely make you excited about what you do." When we go to Mississippi, it's all Mississippi teachers. So it's cool whenever you can go to a regional or national conference and you get to see what teachers all over the United States are doing. Or even just to expand your learning community that far… (2013-2014 MAST participant)*

In short, the interview findings suggest that MAST instructors and programmers implemented their MAST PD to the satisfaction of those who were arguably the best positioned to judge it: the participating teachers over a period of seven years. Most teachers thought MAST was among the best PD they had ever received at the time they were a participant, and even today. When prompted, MAST past participants could single out the benefits of particular opportunities years later. Conversations with MAST alumni about their experiences might give new participants strategies for overcoming potential obstacles (requesting leave time for conferences, etc.) that might get in their way. At the same time, the MAST alums discussed a few ways the program could improve.

Suggested program improvements

While the feedback from teachers has continuously been overwhelmingly positive over the past eight years, alumni offered a few suggestions for the program after years of implementing MAST lessons and materials. The most frequently cited suggestions on how to improve the program include:

- Either too much or less than expected content covered on a topic (N=9)
    - More coverage of life sciences (N=5)

    - More coverage of the Next Generation Science Standards (NGSS) (N=3)
    - Less coverage of space science (N=1)
- Divide the group of teachers based on experience teaching, class level, and/or content knowledge (science content knowledge, pedagogical content knowledge), which has proven to be effective in several studies (Gallimore, Ermeling, Saunders, and Goldenberg, 2009) (N=7)
- Align the course coverage with teacher assessment content (N=7)
- Strategies for incorporating the math component of physics to the classroom (N=4)
- Include a more detailed agenda of the PD courses prior to the program starting (N=3)
- Improved administrative bookkeeping (e.g., payment schedules, email communication about course agendas, etc.) (N=3)

The following quotes indicate additional areas for improvement mentioned by just a couple of alums, such as: a) providing a resource list of materials used during the PD that were not distributed to teachers, b) more hands-on activities in physics, c) more inclusion of computer programming/coding, and d) more course credit leading to a higher teaching degree:

> *For activities that I haven't implemented yet, it would help to have a resource list (where the instructors got their materials and the exact brand and cost). It would also help to have more things provided by MAST or at least more samples. There are some physics activities with electricity and magnetism I'd like to do but I need magnets and compasses and a lab set of multi-meters that don't have the battery soldered in place. I also could use a lab set of the constant velocity cars and equipment to teach dynamics. Or, possibly MAST could order materials on request, or buy some materials in bulk at a reduced cost to provide to schools. I know they have a room to check out supplies but I live a long distance from JSU and it is not convenient for me to plan when I have to wait on a shipment to be delivered and then pay to have it shipped back. (2010-2011 MAST participant)*

> *I could have benefitted from more physics hands on activities with electricity and magnetism, optics, and light. We always seemed to be rushed through those activities. What if MAST could set up a time that teachers could build some of the devices that we were shown, like the PVC rocket launchers. We could make those during MAST if they would provide the materials and the know-how. (2013-2014 MAST participant)*

> *I want to know more about coding and computer science. (2012-2013 MAST participant)*

> *Have teachers come away with a master degree science teaching. This would be the greatest. (2013-2014 MAST participant)*

Alumni encouraged minor refinements to the content covered, greater emphasis on NGSS, improved alignment with course and assessment content, support with lesson implementation, and more structure and organization with regard to teachers' skills, knowledge, and administrative support. Conversations with more MAST alumni about their experiences might give MAST programmers strategies for refining the PD model. In addition, talking to teachers who have implemented the most MAST lessons, and attended the most PD courses, could help inform the program's structure.

Our evaluation data from previous years have demonstrated the following trends: MAST helps give teachers strategies and materials that they use in their classrooms in an effort to engage students in hands-on learning. Results in the past have shown small to moderate improvements among teachers in the following areas: confidence in knowledge of physical science, earth science, and astronomy, confidence in using MAST pedagogical techniques (e.g., inquiry), personal science teaching efficacy, and science content knowledge. Collectively, student results in the past showed small, significant group-level gains in the following areas: confidence in knowledge of physics and earth science and physical science content knowledge.

It is important to note, though, that some educators have questioned highlighting content knowledge in professional development evaluations. The pressure to document yearly achievement may blind evaluators, funders and policy-makers to other important outcomes necessary for the sustainability of school, district or state science initiatives (St. John, 2013). Within MAST's various instantiations, for instance, we have heard numerous stories of teachers who have become administrative leaders and science advocates in their departments and schools. Inspired by their experiences in MAST, these teachers have disseminated what they have learned and promoted instructional change on a larger scale. We are in the process of documenting teachers' post-MAST activities more systematically and plan to explore the role that MAST may have played in any scaling efforts. With this in mind, our current evaluation included surveying MAST alums, followed by interviews, to help us identify these and other long-term outcomes, thus broadening our evaluation horizon beyond just test scores.

With this study, we sought to explore how MAST helped continue to shape and improve the teaching practices and skills of MAST alumni. The results indicate that the program has maintained a lasting impact on a selected group of MAST past participants. The findings, extracted from our survey analysis and interviews—and consistent with MAST's theory of change—show that teachers have, in fact, improved their learning, and the benefits of this program have sustained. Finally, it is possible that students of MAST-trained teachers may improve their knowledge across a variety of sciences, even if their teachers participated in the PD years prior; additional research is necessary to link these findings to MAST. Past participants are continuing to implement MAST lessons, use MAST materials, and still praise the improvements in their content knowledge and teaching practices.

While it is difficult to examine what outside factors over time may have effected past participants' feelings related to MAST having improved their teaching and knowledge over time, it is significant to note that the positive feedback and reported impact of the program remains over a long period of time. The long-term contact between the in-service teachers and

MAST, through continued feedback, online blogs or courses, might help provide teachers with the extra support they may need. Ongoing support and contact with alums can help teachers better bridge the gap between the MAST PD model and theory of change, and the classroom application of what they learned.

Unexpected Findings - PD Instructors and observers and expansion of MAST model

The MAST PD instructors, many of whom have been teaching these courses for several years, are responsible for the following: (a) planning, developing and executing PD courses that are aligned with the Mississippi State Curriculum Framework and NGSS, (b) ensuring that lessons are executed successfully, and (c) to monitor and adjust the professional development program and experience from beginning to end based on teachers' learning levels. Seen as "the experts" in various science domains and pedagogical strategies, this role involves balancing the worlds of the teachers with those of their unique set of Common Core State Standards, while being knowledgeable of the elements inherent in each unique community. For the teacher, the PD instructor must weave together their own knowledge of the classroom, science content knowledge, and an understanding of how teachers learn, while helping teachers link the science they are learning to their own classroom teaching. Therefore, the evaluation begs the question, what do the MAST PD instructors take away from their experience, and how does their experience help inform and assess their own practice? In the upcoming evaluation, REA will incorporate the feedback of the MAST PD instructors in an attempt to gather preliminary data on how their involvement in the program, and incorporating the feedback of teachers and program staff, helped inform their curriculum and influence their own professional development.

In addition to the PD instructors potentially benefiting from their involvement with the program, JSU faculty observers may have also reaped benefits. Since 2009, JSU faculty members from the Department of Physics, Atmospheric Sciences & Geoscience (PASG) were recruited to observe each PD session. These faculty members received ongoing training from REA before observations began. Current research claims that in pursuit of improving teaching practices, the best thing for teachers to do it to look outside of their own classrooms. According to Star and Strickland (2007), observing other teachers is a key element of development, and it improves teachers' own self-awareness of their skills and helps to identify areas for future growth. The future evaluation also begs the question, to what degree have the faculty observers' attitudes toward teaching science changed since being an observer? Also, to what extent have faculty observers implemented strategies and resources into their own classrooms by watching other teachers? REA will continue to explore how MAST has an impact on PD instructors and faculty observers. It is our belief that not only science teachers reap benefits from the program, but instructors and observers as well.

The MAST PD model moves beyond prior published work. First, unlike past studies, the main intervention is aligned with specific approaches associated with successful PD in the current literature, including a strong content focus, active learning (inquiry-based activities, student learning; coherence (alignment with the Mississippi State Standards); duration (graduate course credits); and collective participation (collaborative learning in school-based context) (Desimone, 2009; Garet, 2001). Additionally, the MAST PD model utilizes pedagogical strategies identified in science education literature that is considered effective for science K-12 instruction. Lastly, our current study sought to determine if short-term PD gains and impact have staying power (> 1 year later) using self-reported data and, with our next study, outcome data.

(II) Perspectives on Program Implementation

Introduction

Participant ratings are one indicator of the quality of a professional development program's implementation (O'Donnell, 2008). In the MAST end-of-program evaluation, teachers answered questions about their overall impressions of the professional development and their opinions of post-summer workshop resources (e.g., classroom visits, organizational memberships) designed to provide additional instructional support. Longer-term analysis suggests that teacher gains over a period of eight years are long lasting and cumulative. This section summarizes teachers' qualitative and quantitative reviews, arguing that that MAST instructors and staff members established and maintained a relatively high level of professional development quality during this year's operation.

Overall Value of the MAST PD

Collectively, teachers rated MAST highly. Over half of participants described MAST's overall value as "among the best PD experiences" and nearly 87% strongly agreed that they would recommend the program to other teachers. General ratings and recommendations are indicators of professional development quality, but lack specificity about what might make a program successful. Evaluators therefore chose to measure implementation not only by gauging participants' overall reactions, but by assessing MAST's alignment with teachers' past and present experiences and teaching obligations.

We scaled six coherence items from the Eisenhower evaluation's teacher surveys (Cronbach's alpha = .64) to see what the MAST teachers thought about their program (Table A1). Teachers generally agreed that MAST was consistent with past PD experiences and present state and district policies. We also calculated the means for each item. Year by year comparisons showed minimal differences, with an average change of .4 points. In other words, the consistency of MAST with self-reported teacher knowledge and state/district policies remained virtually the same over a span of eight years.

Table A1. Consistency of MAST with teacher knowledge and state/district policies (N=345)

Items in scale	Alum Mean (N=345)	SD
(1) MAST was consistent with my own goals for professional development. (2) MAST was consistent with my school or department's plan to improve practice and student learning. (3) MAST was built on other professional development activities I have experienced/attended in the past. (4) MAST was followed up with activities to help me implement my new knowledge and skills in my classroom. (5) MAST was designed to support state or district standards/curriculum frameworks. (6) MAST was designed to support state or district assessment.	3.43	1.2

Response scale: *1 = Strongly Disagree, 2 = Disagree, 3 = Agree, 4 = Strongly Agree*

End-of-Course PD Reviews

Teachers' end-of-course reviews revealed other perceived strengths of the MAST workshops, including the abundance of content-rich, hands-on activities and the opportunity for teachers to experience those activities as students/learners. A total of 214 professional development sessions were held between 2010-2017, on topics ranging from physical science to science classroom preparation. Overall, in aggregate, the majority of teachers (77%) strongly agreed the instructors for the PD sessions created an environment in which teachers were motivated to learn (Table A2). The majority of teachers agreed or strongly agreed that 'the sessions helped me better understand the content knowledge related to the MS Science Framework' (84%), 'the session provided me with useful materials and ideas for my classroom' (89%), and the session was about a topic I needed to know more about' (89%). Alums tended to rate the sessions higher, but not significantly.

Table A2: Overall Session Evaluation (N=59)

To what extent do you agree with the following statement?	Alum Mean (N=51)	SD	Aggregated Mean (N=298)	SD
(1) This session helped me better understand the content knowledge related to the MS Science Framework.	3.73	0.76	3.71	1.03
(2) This session provided me with useful materials and ideas for my classroom.	3.84	0.7	3.75	0.95
(3) The presenter created an environment in which I felt motivated to learn.	3.81	0.71	3.72	0.94
(4) This session was about a topic I needed to know more about.	3.77	0.7	3.69	0.98

Response scale: *1 = Strongly Disagree, 2 = Disagree, 3 = Agree, 4 = Strongly Agree*

The most effective parts of the sessions were: the hands-on activities that teachers could take back to their classrooms, the experiments and visuals, explanations of how to use lab equipment, and classroom management techniques during labs and activities. Teachers also liked how the professional development sessions had demonstrations, discussions, time for reflection, manipulatives, and real life examples of teaching science.

Among the concerns raised by a small minority of teachers, some suggested: making sure each session did not have repetitive activities, less lectures, more organized and thought-out daily plans, agendas and schedules for teachers to reference, and dividing up the sessions by content area and academic skill level. Teachers also would have liked the sessions to be slower in pace, allowing more time to absorb the content and newly introduced materials. Suggestions for future professional development sessions focused on including more discussions, more reflection, activities, and refining the layout and timing of the sessions. Teachers indicated they would have liked more time for hands-on activities to ensure that they fully understand them, as well as breaking the day into multiple sessions with more breaks. Teachers wanted the sessions to be more focused on the content and teaching strategies. Lastly, teachers suggested putting handouts on a flash drive or shared drive prior to the sessions to allow teachers to easily access to the materials before, during, and after the sessions for reference.

(III) Teacher Impact

Introduction

MAST goals were to improve teachers' content knowledge, teaching practices, and self-efficacy in science, all of which are believed to influence students' content knowledge and attitudes toward science (self-efficacy and interest). In an earlier section of this report, we described the program's effect on self-reported teaching practices. This section uses content test and survey data from eight years, including control group data (before and after exposed to MAST) to examine the extent to which teachers who participate in MAST demonstrate growth in science content knowledge and teaching efficacy.

Content Knowledge

Evaluators measured all teachers' science content knowledge using both MOSART (2010-2013) and an internally developed test comprised of a synthesis of items created by the PD instructors (2014-2017). Each PD instructor created an assessment test that aligned with what they taught. Hence, we selected items from those tests to ensure even coverage of each Big Idea. The science content test served as a multiple-choice measure of physical science content knowledge developed to ensure that the science content aligned with what was being taught during the PD. To determine if there were significant year-to-year differences, we calculated the coefficient of variation. The coefficient of variation measures the group's variability that accounts for their mean. A one-way repeated measures ANOVA was performed, and we hypothesized that content test scores would be higher the last three years of MAST compared to the first four years due to MOSART's level of difficulty. We also expected to see upward score trends during the last three years as a result of program modifications and a more focused PD curriculum provided by the instructors. As stated, the previously used instrument, MOSART, was considered too difficult according to the first several cohorts of teachers. Results showed a significant main effect, *F* (2.35, 27.30)=41.2, p<.01 (Figure A1). Paired t-tests post hoc analyses were run, and showed that Baseline (First MOSART scores) did not significantly differ from Year 4, but significantly differed compared to Year 7 during the 2014-2017 cohort (Figure A2). When we compared science content scores the Control Group, we found significant differences between when this cohort was not exposed to MAST compared to when they were exposed (Figure A3).

Figure A1: MOSART Average Means – Physical Science (N=136)

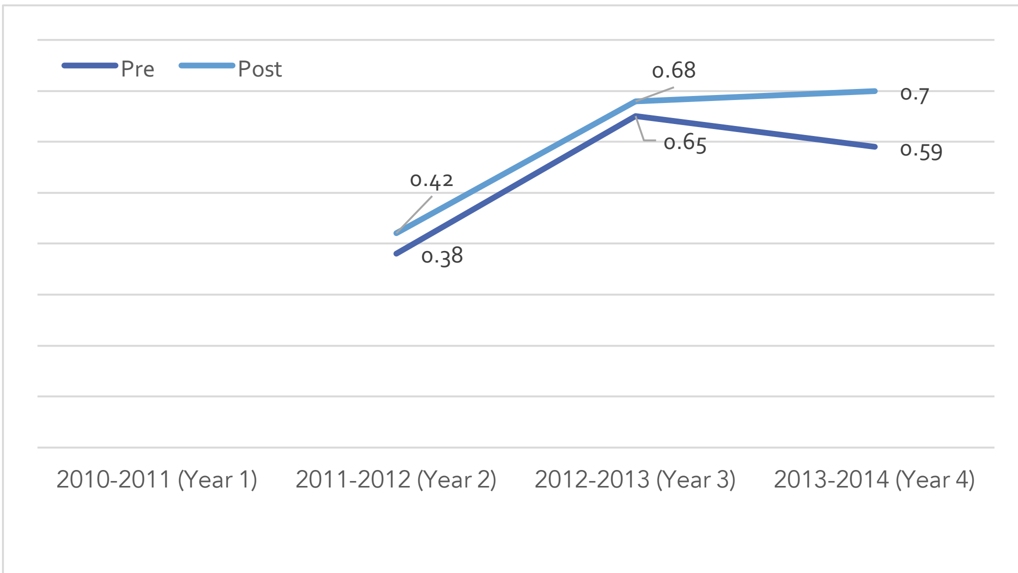


Figure A2: Internally Developed Content Test Scores - Average Means 2014-2017 (N=136)

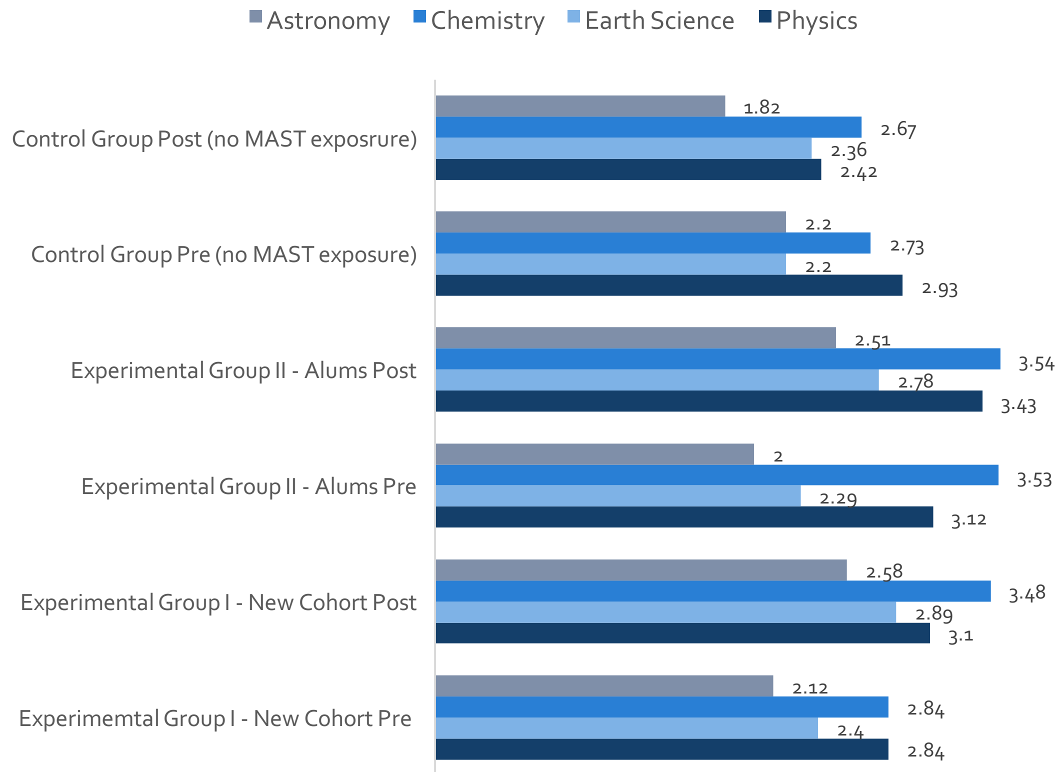
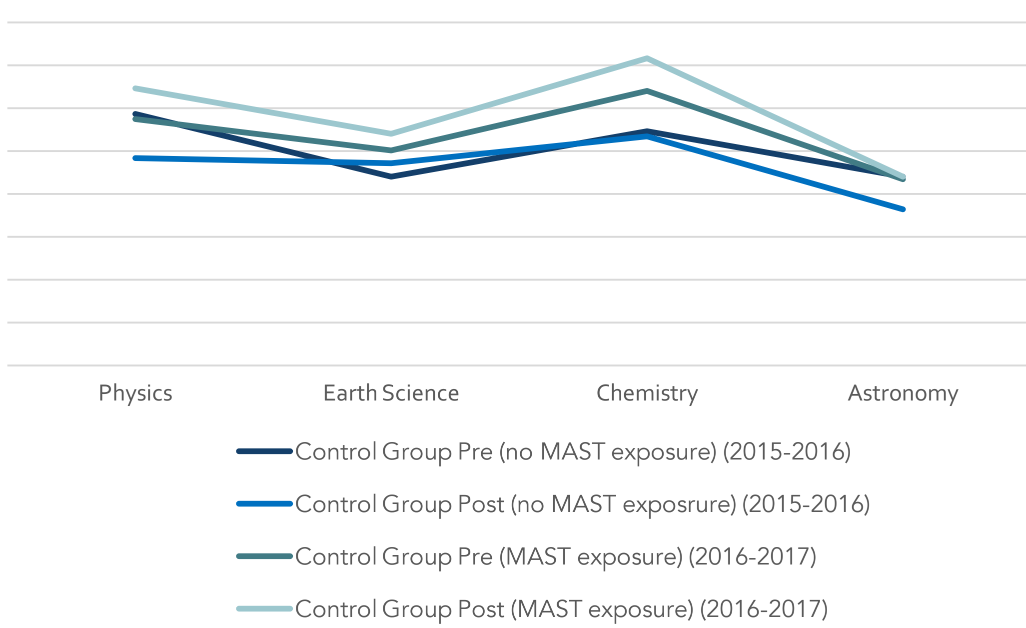


Figure A3: Internally Developed Content Test Scores - Average Means (Control Group) (N=14)



Science Teaching Efficacy

We used several types of general and program-specific questions to assess teachers' efficacy for teaching science (Table A3).

Table A3. Teaching efficacy measures

Scale	Source	Sample item	Number of items	Alpha[6]
Personal science teaching efficacy	Science Teaching Efficacy Belief Instrument (STEBI)	I know the steps necessary to teach science effectively.	7	Pre = .69 Post = .67
Outcome expectancy		If students are underachieving in science, it is most likely due to ineffective science teaching.	5	Pre = .6 Post = .64
MAST teaching techniques	Internal	I feel confident that I am employing the best pedagogical practices when teaching science.	5	Pre = .69 Post = .77
Subject matter knowledge confidence		How confident are you in your knowledge of the following subject areas?	4	Pre = .71 Post = .74
Teaching ability confidence		How confident are you in your ability to teach the following subject areas?	4	Pre = .63 Post = .69

We selected items from the two subscales of Riggs & Enochs' (1990) Science Teaching Efficacy Beliefs Instrument (STEBI) in order to measure teachers' (a) personal science teaching efficacy and (b) science teaching outcome expectancy. The former scale evaluates "teachers' confidence in their own abilities" (Riggs & Enochs, 1990, p. 626), while the latter measures teachers' perception that their actions will improve student learning. The STEBI instrument contains 25 items, but because it was one of several sets of questions we planned to include in our pre and post measures, we were concerned about survey fatigue. We therefore cut the scales in half by selecting the six or seven items per scale with the highest factor loadings according to Riggs and Enochs (1990).

[6] Cronbach alpha scores were calculated at two different times (pre and post) to assess internal validity.

We also included three types of MAST-specific efficacy items. We constructed five items to assess teachers' confidence implementing pedagogical strategies covered in MAST such as integrating technology, differentiating curriculum and teaching students to use hands-on materials. We also asked teachers about their confidence in their knowledge of four physical science subjects (physics, chemistry, earth science and astronomy) and their confidence in their ability to teach those subjects.

In aggregate, there were statistically significant gains from pre to post on all survey scales except personal science teaching efficacy and outcome expectancy for alums and the new cohort. That is, teachers reported increases in subject-matter confidence, teaching ability confidence, and confidence for MAST pedagogical techniques. We ran repeated measures analysis of variance (RM-ANOVA) to determine whether there were significant differences by year and by cohort (control and experimental from Years 7 & 8) with respect to teachers' confidence in their ability to teach science and their confidence in their physical science content knowledge. We found a statistically significant differences between teacher self-efficacy when we compared years 3 and 8, F (1,261 = 3.81, $p < .05$), and statistically significant differences when we compared experimental membership outcomes to control group outcomes, $F(1, 76) = 47.8$, $p < .05$, with minimal main effects for both comparisons. We did the same analysis for teachers' confidence in their physical science content knowledge and their ability to teach science. Results were not statistically significant across PD year. Statistically significant differences were found between teachers' ability to teach science when comparing experimental outcomes to control group outcomes, $F(1, 76) = 42.9$, $p < .05$.

It is also worth noting that four out of five scales showed significant increases from pre to post for the control group, after being exposed to MAST (compared to no scale differences from pre to post before being exposed to MAST). There was a statistically significant increase from pre-program scores for the control group (with no MAST exposure) to post-program scores for the control group exposed to MAST, $t(374) = 1.65$, $p < .05$. This finding is significant – it shows that for teachers with no exposure to MAST did not show pre and post differences in science teaching efficacy, however, after being exposed to MAST, most of the scales yielded significant changes from pre to post. This finding clearly indicates that MAST's PD makes a difference in science teaching efficacy compared to non-MAST-exposed teachers.

We averaged the annual means by each efficacy subscale. Overall, in aggregate, teachers over the course of eight years tended to feel more confident with teaching the science curriculum, and personal feelings of science teaching efficacy, but less confident with the science content and their ability to teach science. These differences annually are minimal, however, and were not statistically significant. In other words, average means by efficacy subscale remained consistent. Breaking down subject-matter knowledge confidence and teaching ability confidence by subject area, by PD year, we found statistically significant decreases from the 2011-2012 cohort compared to the prior and following years (Figure A6). The control group showed a significant decrease in their physics content knowledge. It is worth noting that in instances where Control Group teachers showed significant gains in their confidence in science content knowledge and their ability to teach science, we saw greater gains after exposure to MAST in 2016, $t(353) = 1.66, p < .05$

Figure A4: Teacher Self-Efficacy (Confidence in Knowledge and Ability to Teach Science) – Average Means (N=291)

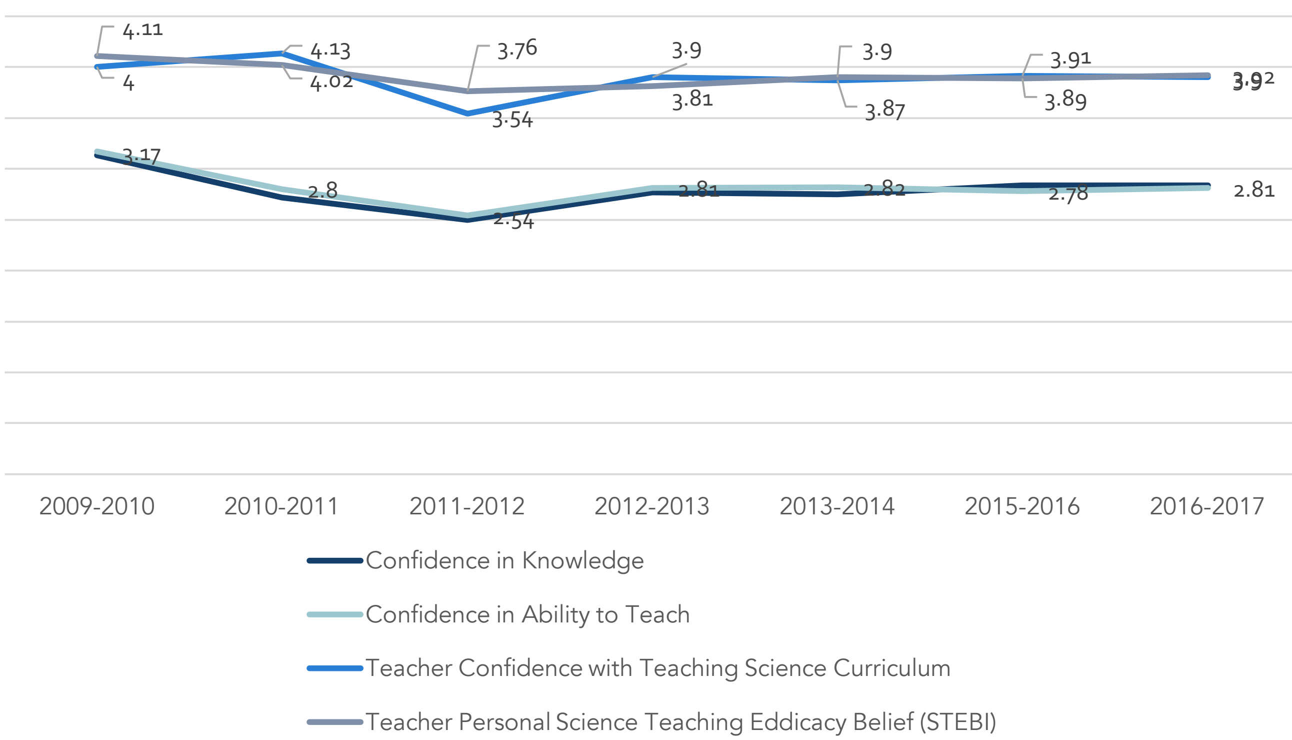


Table A4. Regression Analysis Table – Relationship between background variables, teacher knowledge, teacher practice, student efficacy, teacher efficacy, and use of MAST materials, professional learning communities and activities, and PD support at schools (N=277)

	PD Supported by Administration	Professional Learning Community	Content	Use of MAST materials	Changes in practice	Student efficacy	Teacher efficacy
Gender (F=0; M=1)	0.00	0.03	0.01	0.03	0.00	0.00	0.02
Number of times in MAST	0.01	**0.16**	**0.08**	0.00	**0.12**	0.01	0.00
PD Supported by Administration		**0.19**	0.00	0.03	**0.09**	0.11	**0.09**
Professional Learning Community			0.0	0.01	0.05	0.04	0.07
Content				0.03	**0.11**	0.04	**0.10**
Use of MAST materials					**0.21**	0.0	0.03
Changes in practice						**0.18**	0.0
Student efficacy							**0.26**
R-square Adjusted	-.02	.36	.07	.19	0.57	.36	.29

We used regression analysis to examine the relationship between components of MAST's model. Regression incorporated a least-squared algorithm in an effort estimate the strength of relationships between the dependent variables (content test scores, efficacy survey scores, etc.) and independent variables (gender, PD support, etc.). Table A4 shows the standardized regression coefficients and significance levels for each predictor in the model. With this approach, we are able to compare the strength of these associations. For instance, a standardized beta coefficient 0.21 is three times as strong in its effect as one of 0.07. The regression shows how each variable contributes to MAST's model and program implementation. The variables that are in bold highlight that variables related to teacher efficacy, PD support, professional learning activities and use of MAST materials contributes to predicting levels of student efficacy. The table also illustrates that gender had zero impact of predicting these relationships. The level of reported professional learning activities generated and encouraged by the program, such as attending conferences, was a mediating variable in and had significant effects on teacher knowledge and practice.

Conclusions and Discussion

Our analyses of the teacher content test and survey data provide some evidence supporting the teacher outcomes section of MAST's theory of change, and previous literature review. High school teachers appear to be making significant gains on most of their respective content tests, and teachers collectively seem to be increasing most of the measured aspects of science teaching efficacy. It is worth noting that over a span of eight years, science teaching efficacy and content test score seemed to slow minimal upward trends, with the exception of one year. In addition, we found a statistically significant difference between teacher self-efficacy when we compared experimental outcomes to control group outcomes, and between teachers' ability to teach science when comparing experimental outcomes to control group outcomes.

The content knowledge and efficacy findings are generally consistent with MAST's theory of change, and the control group findings help confirm that MAST may if fact be responsible for those outcomes. We can be fairly confident that the content test results and efficacy gains are the product of MAST workshops, since the control group teachers took the tests immediately before and after a non-MAST academic year, and before and after the summer sessions during their year of exposure. In addition, because we assessed efficacy before the MAST workshops and at the end of the school year, there may have been any number of contextual factors (e.g., classroom composition, school climate, district policies) besides MAST that may have affected teachers' attitudes.

We have several years of MAST data demonstrating changes in teacher efficacy on a number of measures. We also have case studies of Project MAST teachers who say that the program gave them the confidence to take risks with their teaching (Cooper, Bass, Mushlin & Fadavi, 2011). Lastly, we have survey comments from a number of teachers about their increased confidence, and testimonials from teachers who presented at an annual MAST administrator seminar. Together, each of these sources of evidence suggests that MAST's professional development model may in fact be changing teachers' confidence for knowing and teaching physical science. In any case, we showed that there is a difference between the outcomes of those exposed to MAST compared to those teachers who were not.

B. Changes in Teacher Practices and Use of Materials

Introduction

Evaluators used two primary sources of evidence to explore changes in teacher practice: two post surveys about the use of MAST materials and teaching strategies. This section presents the results of the teacher surveys in aggregate, while a later section incorporates teachers' lesson plans into the analyses.

Use of MAST Materials

At the end of the school year, most teachers completed an online survey in which they identified the percentage of MAST materials they had used to teach the same activities they had done in the professional development workshops. In aggregate, teachers tended to use the physics materials the most and the astronomy materials the least (Figures B1 for physics material use). When separating out the MAST alums only, they tended to use the chemistry materials the most and the astronomy *and* earth science materials the least (Figures B2).

Figure B1. Teachers' use of MAST materials – Physics (N=284)

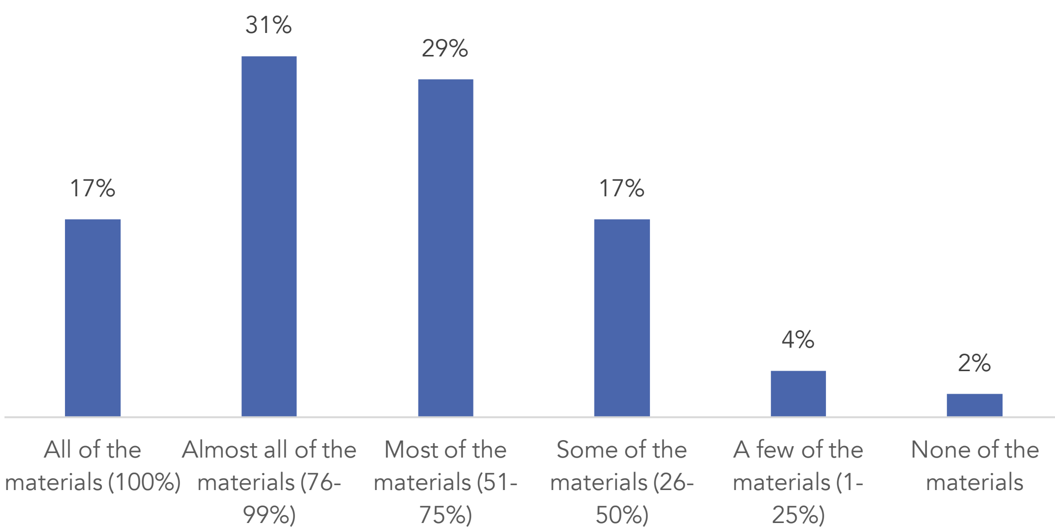
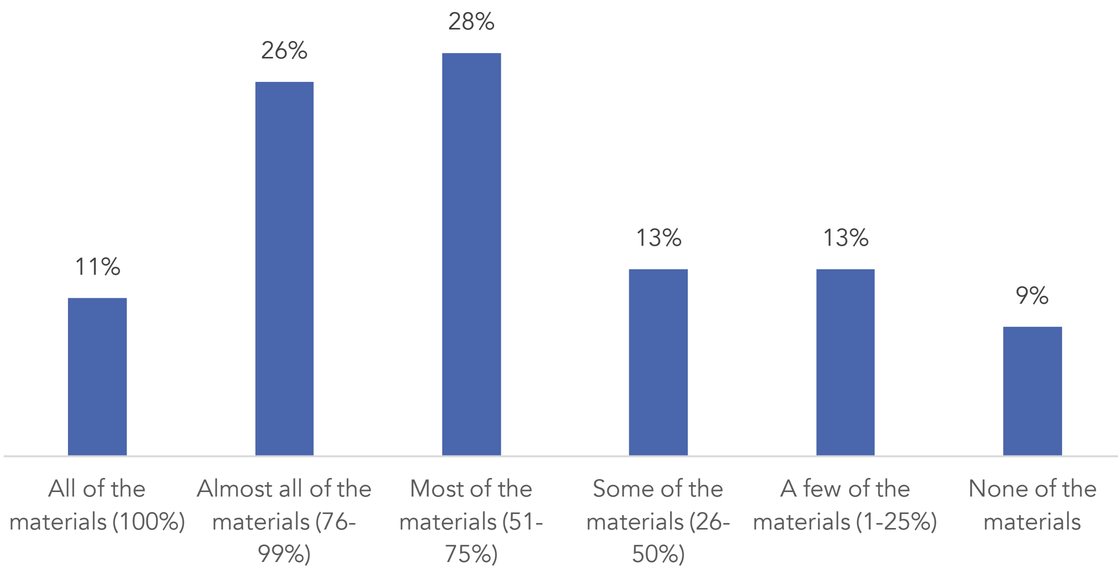


Figure B2. Teachers' use of MAST materials – Chemistry (N=63)



In aggregate, between 2009-2017, a little over half (52%) of teacher participants (146 teachers out of 281) identified the Vernier probes and equipment as some of the most useful materials they had received, and as being especially valuable:

> *I used the Vernier LabQuest units extensively in chemistry, physics, and physical science classes. The lessons taught with Vernier included food calorimetry, heat of solution vs. heat of reaction to teach differences in physical and chemical changes, temperature survey of campus with a graph of Fahrenheit vs. Celsius and determining the conversion equation from the equation of the line of best fit, and the temperature changes during phase changes.*

> *I have used the Vernier LabQuest units extensively in chemistry and physics. Labs that we have done include Calorimetry of food, temperature survey of the campus and graph of Fahrenheit vs. Celsius to derive the conversion formula, heat of solution, endothermic and exothermic reactions different from the ones learned at MAST, and thermodynamics to back calculate the flame temperature of the Bunsen burner. All these required the temperature probes only and LabQuest units I acquired through MAST and other grants. I also used science notebooks in all my classes this year (physics, chemistry, physical science).*

In addition, about 28% of teachers cited the chemistry materials as being the most useful, including activities for teaching biochemistry, chemical reactions, and properties of water.

> *There was an activity that involved teaching the properties of elements in the periodic table. The students created cards that included information about the element. After creating the card with the element name, symbol and the Bohr model, the elements were added to a wall in order. The students analyzed to organization of the Periodic Table. I added to this when I taught electron configurations because the students understood that each element had one additional electron and that ions had the same electron configurations as other elements because they had lost or gained electrons. For instance, they know that Fluorine (when it gains one more electron) has a negative charge and its configuration looks like Neon which has ten electrons also. However, because the number of protons is an element's "fingerprint", it is still fluorine. They were able to use the periodic table to determine number of electrons for the atom or ion present and place them on a chart to determine the configuration. Ideas for the chart was presented by MAST.*

> *I used the Chemistry materials to teach a lab on how antacids affect the human body in Biology.*

> *Chemistry material was used in various ways in my classes. Chemistry materials were used to either introduce a lesson, in the middle of the lesson or as an inquiry activity. The topic on pressure, volume and temperature, the students were thrilled to use the hand boilers. The hand boilers were used as inquiry activity where the students experiment, analyze and report their findings. The students were then asked to write an essay on the same activity as to how the hand*

boiler works as one of the activities to improve the reading and writing skills among the students.

Other teachers simply appreciated all of the materials, especially since they freed up time to focus on other areas of teaching and since some teachers mentioned having a small budget.

All of the materials have been wonderful because I have been able to use more inquiry-based learning skills and the materials have enabled me to do more hands-on activities. (Alum)

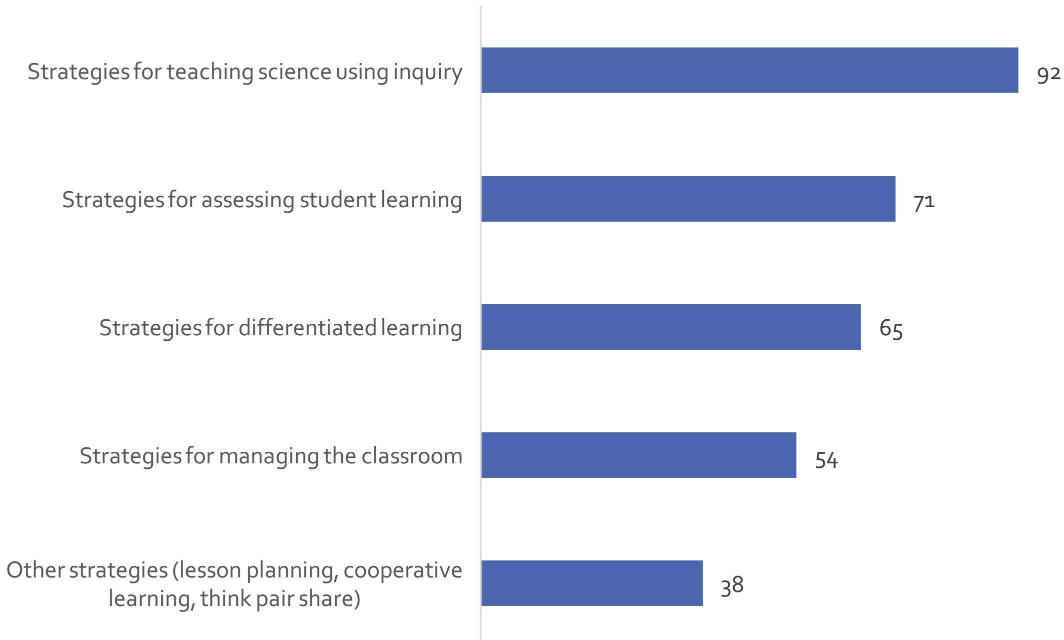
All the supplies and demonstrations were beneficial. I gained fresh ideas from the presenters and my peers. All the supplies helped me stretch my classroom budget, and even made things available that could not have purchased on my STEM budget. I feel that I grew professionally as a result of the MAST cohort. Every piece of equipment, every material, every item, and all the notes proved helpful this year, and will probably prove even more helpful next year as I try to use more student-based inquiry.

Teachers liked the MAST activities because they were easy to use with their students, and easy to replicate. Open-ended comments from eleven teachers indicated that they used lessons in their classrooms exactly as they were taught in the PD. In fact, more than 68% of the teachers disagreed with the statement "It was hard to plan how I would use these materials and activities with my students." Seventy-three percent agreed or strongly agreed with the statement "The difficulty level of the activities was just right for my students – the activities weren't too easy, and they weren't too hard." However, about one third of teachers reported that they either didn't have enough materials for their students, or enough time to practice using the materials. Many teachers reiterated this when describing what would have made it easier for them to implement MAST materials and activities.

Use of MAST Instructional Strategies

Almost all teachers surveyed indicated that they had used at least one of the instructional strategies they had learned in MAST. The vast majority of teachers had employed strategies for teaching science using inquiry, and most had also tried other new approaches for differentiating learning, followed by strategies for assessing student learning (Figure B3).

Figure B3. Teachers' use of MAST pedagogical strategies (N = 288)



**Note: Respondents could select more than one answer; item totals exceed 100%*

MAST's emphasis on science pedagogy and content knowledge appeared to have an especially dramatic impact on some teachers. Seeing how science can and should be taught inspired teachers to try new approaches in their classrooms. Consider the following comments:

> *I loved this program and experience. It has enhanced me is so many ways. I was able to add more labs to my curriculum and expand my own knowledge about what materials are out there for teachers to use. I feel more confident about Earth Science and Chemistry, and I have an appreciation for physics and astronomy. My learning community has doubled, and I feel I have become more well-rounded teaching and professionally.*

> *I am grateful for the opportunity to attend MAST and am confident that it has improved my knowledge and teaching practices dramatically!*

> *I received much needed materials. I was able to incorporate many of the tools into the curriculum. I look forward to working on the Vernier products for next school year. It has been one of my goals to conduct more labs. I am thankful for being given the opportunity to*

complete the program and I vow to expose my students to as much student centered, technology related activities as possible in the coming years.

Project MAST has made me an effective teacher. Thank you!

Additional Changes in Practice: Pre and Post Lesson Plans & Classroom Observations

An examination of teachers' pre and post written lesson plans and observations of teachers' science lessons allowed evaluators to capture some evidence of changes in teaching practice beyond self-reporting.

Written lesson plans

At the beginning of the summer PD, MAST participants were asked to submit a typical science lesson they had taught in the past year. Teachers received a list of six physical science topics from which they could choose: periodic table; matter (substances, atoms, molecules, compounds); force, motion, and/or Newton's Law's; electricity and magnetism; rocks, minerals, and fossils; or the solar system. They were asked to select their own topic if they did not teach any of the listed subjects.

Teachers received a template, instructions and an example to ensure that their plans contained information about: a) the objectives and standards they covered, b) the materials they used and procedures they followed, c) any strategies they used for differentiated instruction, assessment and extension, and d) persona reflections on the strengths of the lesson and areas for improvement. They resubmitted those lesson plans – preferably on the same topic if they taught it that year – after the MAST training was completed. If the teachers had not taught that same lesson, they were asked to submit a plan on any of the six physical science topics listed previously. The post lesson plan template was identical to the pre, except for one additional question about what (if anything) teachers had changed in their lessons as a result of their participation in MAST. The template asked teachers to provide basic classroom information such as a list worksheets and handouts, materials, and standards and big ideas addressed during the lesson. Teachers also provided a description of the lesson from the introduction to the end, how they might differentiate instruction, and assessments and extensions to the lesson. At the end, teachers reflected on how their lesson changed as a result of their participation in MAST, the strengths of the lesson, and where they would still like to improve.

Two hundred and thirteen MAST participants submitted lesson plans for the post analysis portion of data collection. Of those 213 lesson plans, 66% indicated they changed their lessons as a result of what they learned through the MAST program. Of the 33% (N=72) who did not change their lesson, 38 teachers stated they did not change that particular lesson, but changed other lessons throughout the year based on the work they did with MAST. After participating in MAST, teachers described the changes they made to their lesson plans:

> *I started the unit with a hands-on activity instead of starting with notes and ending it with activities. This was done to give students a visual to refer back to, to help them understand the concept.*

> *My lessons have been more student centered. I allow them to work together more and to answer their own questions, instead of me always giving them the answers.*

> *Yes. It was all demonstration before, but now I incorporate group discussion and student performance more often. I also realize that inquiry is better for students learning and allow the students to struggle through the process alone first before leading them to the correct answer.*

> *We used more actual products and did more student guided questions. I allowed students to choose topics/items to research. I made these changes to make the lesson more meaningful and to be less of my giving ideas and more student centered/student directed.*

> *I now write the specific standards on the board for my students to see and understand their importance.*

> *I added Cornell notes for independent study. I changed the order of the lessons by trying to follow the 5 E method.*

Teacher comments suggest the changes they made to their lesson plans due to what they learned at MAST had a positive impact on their students' interest and engagement. The strength of the lessons was described as being more "inquiry based," "hands-on," and "connected to real world situations."

The manipulative worked well. Even students who did not need to use them were excited to learn and share with their classmates.

Differentiated instruction allows for students to use inquiry skills and they are self-motivated to make the circuit work.

The students were more involved in the unit because they really enjoyed this lesson.

Looking specifically at "process" of the lesson plans, 87% of teachers described having students participate in hands-on activities with the majority (89%) having worksheets for students to complete as part of the activity. Class discussions (38%) and teacher lead lectures (15%) were part of the introductions, main activities, and conclusions of the lessons, however it should be noted the majority of lessons were comprised of more than one category (teacher demonstration, hands-on activity, lecture based, class discussion, and independent work).

When prompted about what teachers would like to improve upon in their lessons, responses varied from trying different teaching strategies to changing specific components of a particular lesson. Teachers said they would like to include "more hands-on activities," "have actual models for the kinesthetic learners," and "have my students do more research out of the class." More specific comments included:

I would like to help my students feel more confident when completing the student-guided activities.

Better implementation on my part through practice.

Use more practice with examples in the lab, but usually I do not have time for this.

REA has expressed interest into looking further into the materials teachers used in their lessons throughout the school year and if those materials were used at the MAST professional development sessions. If alignment exists between actual materials used, it would be wise to incorporate video footage of reenactment in an effort to document further evidence that teachers are in fact using and implementing what they learn from MAST.

C. Student Findings

Introduction

In this section, we answer the question "To what extent do the students of MAST teachers improve their (a) science content knowledge and (b) self-efficacy for and interest in learning science?" Each outcome is described in turn.

Content Knowledge

Between 2010-2014, we used MOSART to test teacher and student science content knowledge. After the first iteration of adopting this measure, many teachers voiced concerns over the tests level of difficulty not only for themselves, but for their students as well. We later realized that assigning content-specific and high-school-level tests to students was not the solution, nor assigning middle-school level physical science tests. The core of the issue surrounding this particular assessment tool centered around PD curriculum alignment. Not only was MOSART developed to measure misconceptions in science (which was not covered in MAST's PD), the science content itself was not aligned with the science content covered in the PD or the Mississippi. We realized that it is critical for the science content assessment tool of choice to align with what is being taught to teachers. Figures C1-C3 demonstrate during the years of using MOSART, students showed very little gains from pre to post, and oftentimes demonstrated losses by the end of the school year in certain subjects. Figure B6 shows that students made greater gains from pre to post. We think these shifts in gains over the years speak to the lack of alignment between the PD curriculum and the assessment used to measure progress.

Figure C1. 2011-2012 Student Content Test Scores

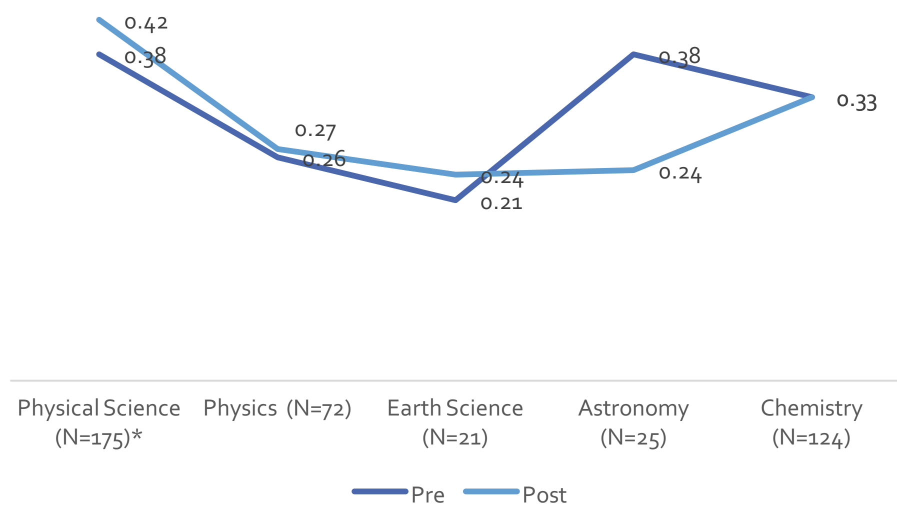


Figure C2. 2013-2014 Student Content Test Scores

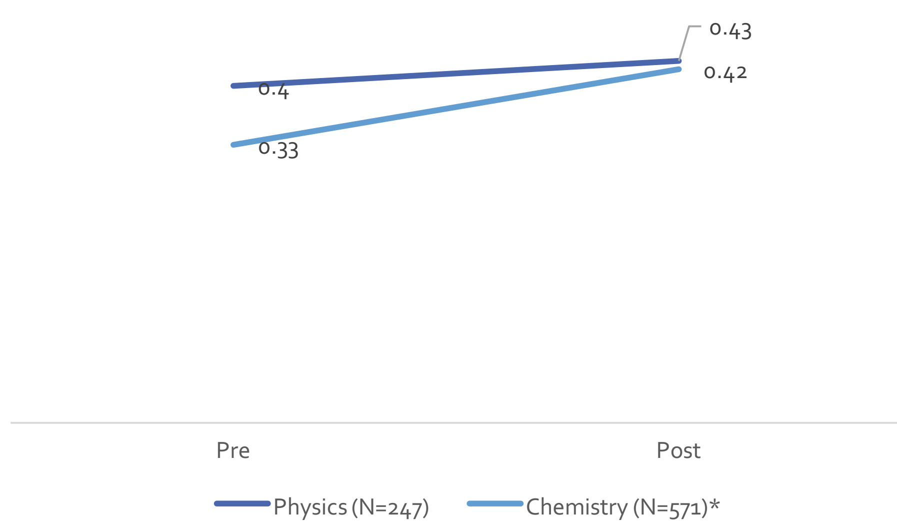
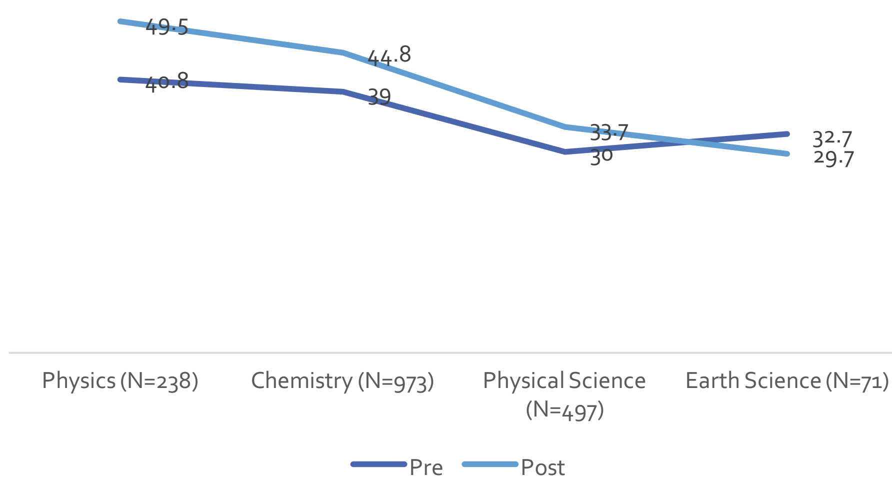


Figure C3. 2015-2016 Student Content Test Scores



Squires (2012) argued that alignment means that the curriculum is designed to make sure that assessments and standards coverage are addressed in the instructional process. Hence, the tested content needs to be covered in instruction, or students will not have the opportunity to understand the tested content. This speaks to evaluating the effectiveness of PD sessions as well. In this section you will see snapshots of student outcomes as they pertain to the tool used that year. We decided in 2014 to adopt internally developed tests for teachers and students that were aligned with the content taught in the PD; the tests were developed by the PD instructors to ensure that this alignment occurred. The student content test results reported in the current report, over the course of eight years, should be analyzed with the changes in assessment tools.

MAST's theory of change predicts that students of MAST-trained teachers will significantly improve their science content knowledge from the beginning to the end of the school year. To test this assumption, evaluators asked teachers to administer chemistry and physics tests to their students (2014-2017), and MOSART middle-school level physical science tests. For this analysis, we have only incorporated the student data while using the internally developed science content scores. These tests were comprised of multiple-choice items, taken from science content tests created by the teacher PD workshop instructors.

Table C4 summarizes student scores by subject. Students tended to score lower on the physical science and earth science tests, with scores averaging between 32 and 37 out of 50. We ran paired-samples t-tests to evaluate the statistical significance of the observed pre-post differences. We found minimal gains from pre to post, but differences in scores were not statistically significant. By teacher group, student scores were similar in range. Statistically significant gains were found from pre to post of MAST alum students, t (846) = 2.02, p < .05. Across subjects and teacher group, students tended to score higher on the post tests, including control group students.

While students scored higher on the post-tests, that alone can't explain the differences in gain between the two subject groups. We would probably need to identify other covariates, such as teacher background, teacher content knowledge or student demographics, to explore and explain the underlying causes of the test-subject differences. In aggregate, the results indicate that students are making shifts in their physics and chemistry content knowledge. The student content test scores between 2010-2016 are noteworthy. Collectively, students of MAST-trained teachers are learning science, though it is unclear from the student data alone how the professional development is responsible for the observed outcomes.

Table C4. Student content test performance scores 2014-2017 – by Subject (N=3,442)

		Pre	Post	df	t	ES[7]
Physics						
	Mean	36.1	38.7	880	2.17	0.06
	SD	18.6	17.5			
	N students	881[8]				
	N teachers	39				
Chemistry						
	Mean	32.9	33.4	1,381	1.65	0.13
	SD	19.9	18.6			
	N students	1,382				
	N teachers	93				
Physical Science						
	Mean	32	32.9	952	1.92	0.1
	SD	16.7	15.1			
	N students	953				
	N teachers	59				
Earth Science						
	Mean	29.6	30.1	225	0.84	0.17
	SD	.96	1.04			
	N students	226[9]				
	N teachers	14				

*$p < .05$

[7] ES = Effect size, measured by Cohen's *d*. Traditional interpretations for Cohen's *d*are 0.2 for a small effect, 0.5 for a medium effect and 0.8 for a large effect (Green & Salkind, 2005).

[8] Paired samples t-test use the same N from pre to post.

[9] Paired samples t-test use the same N from pre to post.

Each year, evaluators measured students' efficacy for learning science with surveys that combined internally-developed items with scales from published instruments (Table C5). We used a five-point scale to measure students' interest in the four physical science content areas covered in MAST and used a four-point scale to measure their confidence in their knowledge of those same subjects. The survey also included two seven-point scales from the Motivated Strategies for Learning Questionnaire (MSLQ); self-efficacy for learning and performance and control of learning (Pintrich, Smith, Garcia & Mc Keachie, 1991).

We also asked students about their interest in physics, chemistry, earth science and astronomy. We expected that changes in teacher confidence and increases in hands-on, inquiry-based science teaching might make students more interested in physical science.

Table C5. Summary of student efficacy measures

Scale	Source	Sample Item	# of Items	Alpha
Confidence in Knowledge	Internal	How interested are you in each of the following (Earth Science, Physics/Physical Science, Astronomy, Chemistry)	4	Not Scaled
Interest in Science		How interested are you in each of the following? (Earth Science, Physics/Physical Science, Astronomy, Chemistry)	4	Not Scaled
Self-Efficacy	Motivated Strategies for Learning Questionnaire (MSLQ)	I'm confident I can understand the basic concepts taught in this course.	7	Pre = .68 Post = .71
Control of Learning		It is my own fault if I don't learn the materials in this course.	5	Pre = .73 Post = .7

Student Survey Scales: Pre to Post Comparison – Efficacy, Content and Interest in Learning Science

Table C6 shows the means and standard deviations for each of the student survey scales from pre to post. As can be seen below, students' academic efficacy increased slightly (in aggregate), with a low effect. For control of learning scores there was virtually no change from pre to post. Both increases were not significant.

Table C6. Students' science self-efficacy and interest, all cohorts

Scale	N	Pre		Post		t	df	Effect size
		M	SD	M	SD			
Academic Efficacy	6489	5.27	24.9	5.41	23.4	-0.79	6488	0.00
Control of Learning	6314	4.91	26.5	5.19	25.3	1.05	6313	0.02

Scale: 1=Not at all like me, 7=Very much like me

Over a span of eight years, student efficacy for learning science and content test scores remained statistically unchanged, but consistent. We focus on the findings that include Control Group data (2016-2017), as this comparison demonstrates a significant effect when comparing pre-program (no MAST exposure) scores to post-program scores after being exposed to MAST. There were significant gains in three out of four subjects for Control Group students (Table C7). Between 2016-2017, at the end of the academic year, New Cohort students' interest in chemistry improved significantly, their confidence in their knowledge of all subjects did not change from pre to post; both of these findings displayed low effects (Table C8). Thus, Alum students' interest in earth science and chemistry increased significantly. For the Control Group, student showed changes in science interest and confidence in learning science across all subjects. Hence, across all groups, students' confidence in all subjects did not change from pre to post, with the exception of the control group. These results are different from the teacher surveys, in which respondents gained confidence in nearly all subject areas. The timing of the student surveys may have confounded the results. The students, most of whom were in physics and chemistry classes and took content tests for both subjects, completed the post survey shortly after taking a content test. They may have felt less confident about the subjects covered on the on the test while their interest and confidence in astronomy and earth science changed in the opposite direction. In the end, the Control Group tended to show the highest gains in science interest and confidence in science knowledge.

Table C7. Student interest in science content knowledge 2015-2017

NEW COHORT Scale	N	Pre		Post		t	df	Effect size
		M	SD	M	SD			
Earth Science	367	2.68	1.21	2.61	1.25	0.77	366	0.05
Physics/Physical Science	369	3.09	1.26	3.02	1.36	0.66	368	0.14
Astronomy/Space Science	369	2.85	1.41	2.84	1.43	0.03	368	0.23
Chemistry	364	3.19	1.26	2.85	1.33	2.64*	363	0.21
ALUMS Scale	**N**	**Pre**		**Post**		**t**	**df**	**Effect size**
		M	**SD**	**M**	**SD**			
Earth Science	766	2.71	1.21	2.57	1.25	2.32*	765	0.1
Physics/Physical Science	765	3.17	1.26	3.11	1.34	0.99	764	0.14
Astronomy/Space Science	763	3.09	1.46	2.99	1.43	1.34	762	0.13
Chemistry	769	3.32	1.38	3.07	1.41	3.57*	768	0.18
CONTROL Scale	**N**	**Pre (no exposure)**		**Post (MAST exposure)**		**t**	**df**	**Effect size**
		M	**SD**	**M**	**SD**			
Earth Science	389	2.76	1.27	3.11	1.31	1.6*	388	0.21
Physics/Physical Science	541	3.16	1.21	3.39	1.29	1.61*	540	0.19
Astronomy/Space Science	417	3.01	1.32	2.96	1.16	1.47	416	0.05
Chemistry	576	3.29	1.27	3.68	1.32	1.65*	575	0.15

Scale: 1=Not at all confident, 2=Not very confident, 3=Somewhat confident, 4=Very confident

*p < 0.5

Table C8. Student confidence in science content knowledge 2016-2017

NEW COHORT Scale	N	Pre		Post		t	df	Effect size
		M	SD	M	SD			
Earth Science	368	2.61	0.92	2.58	0.91	0.54	367	0.11
Physics/Physical Science	364	2.79	1.82	2.72	0.93	0.62	363	0.09
Astronomy/Space Science	365	2.34	0.97	2.36	0.96	-0.2	364	0.19
Chemistry	366	2.73	0.94	2.64	0.96	1.3	365	0.14
ALUMS Scale	N	Pre		Post		t	df	Effect size
		M	SD	M	SD			
Earth Science	768	2.54	0.91	2.49	0.99	0.97	767	0.15
Physics/Physical Science	763	2.76	0.91	2.71	0.96	1.01	762	0.1
Astronomy/Space Science	768	2.38	0.98	2.34	1.02	0.77	767	0.13
Chemistry	766	2.73	0.99	2.72	1.06	0.17	765	0.11
CONTROL Scale	N	Pre		Post		t	df	Effect size
		M	SD	M	SD			
Earth Science	377	2.65	1.14	2.86	1.2	1.64*	376	0.11
Physics/Physical Science	524	2.78	1.28	2.98	1.25	1.64*	523	0.09
Astronomy/Space Science	398	2.36	1.23	2.59	1.34	1.66*	397	0.17
Chemistry	553	2.75	1.19	3.01	1.18	1.65*	552	0.2

Scale: 1=Not at all confident, 2=Not very confident, 3=Somewhat confident, 4=Very confident

*$p < 0.5$

Conclusions and Discussion

The content test data suggests that students of some MAST-trained teachers can in fact make statistically significant improvements. For students of MAST alums, science content knowledge scores on chemistry and physics tests yielded the highest scores and gains. MAST teachers who feel more confidence and comfortable with the content and using particular MAST-taught teaching strategies may benefit students. These results give a broad overview of student performance across four specific subject areas. These results do not tell us how students are doing on specific physical science standards, nor can they explain how any changes in scores might be attributable to MAST.

Overall, the data on student efficacy and interest showed that: students' efficacy improved slightly each year; interest improved in two subjects; confidence improved in each subject; but control for learning did not improve over the year, but neither did it decrease over time. Students started the year feeling fairly confident about their science abilities and maintained those beliefs over the course of the school year. It important to note that students' attitudes may have varied from teacher to teacher and that the collective average masks important classroom-level differences.

Lessons Learned

The following section discusses lessons learned about implementing the MAST model over long term, and what may be considered effective PD from the MAST program and its impact on teachers' learning in the state of Mississippi.

1. Effective implementation of the MAST model involves learning over time, trust building, and comfort with the material. Research on quality PD focuses on the approach that teachers must take when learning new teaching strategies and new material – viewing PD as a process and complex system rather than an event that leads to rapid change. As we have demonstrated with the Alum findings, over time, teachers had time and greater confidence in implementing what they've learned from MAST. While some short-term gains have been found from teachers and students, the long-term change demonstrated by the alums show that the program has lasting effects. In addition, according to Miller et al. (2015), extended PD of several years allows participants to build trust with other educators, expand networking, and heightened comfort with new strategies and material. More time to learn, more time to engage in peer-to-peer reflection and observations, increased feedback, and more time to implement change may lead to stronger outcomes.

2. Learning from experts is essential to teacher and student benefits. Banilower et al. (2007) argued that students' ability to learn science depends on teachers' advanced content knowledge and their ability to convey information in developmentally appropriate ways. Without expert knowledge and insight, teachers might be constrained in developing scientific engagement and thinking.
3. Teachers must learn from one another to improve practice. MAST teachers often discussed the importance of peer-to-peer learning and interaction, collaboration, and reflection. High school teachers may become accustomed to working independently when it comes to teaching and managing their classes. MAST incorporates and encourages reflection, small-group projects, and candid discussions about teacher practice and how to best approach student learning unique to the state of MS. In this learning environment, teachers participated in professional learning communities with a shared understanding of their long-term teaching goals – to improve student outcomes and achievement.
4. Teachers can demonstrate competency, mastery, and growth in a variety of ways. MAST has proven the long-standing argument that there is not a "one-size-fit-all" approach to PD, teacher learning, and effective practice. MAST gave teachers the freedom to customize their learning in a way that suited them and, importantly, their students. Teachers have demonstrated growth in a number of areas, including content knowledge, teaching efficacy, learning efficacy, and professional learning practices with gains in some areas but not others.
5. Post-program support and outreach could maximize teacher and student impact. The MAST alums provided the strongest evidence of the program's long-term impact. Some of the most frequently cited requests from the program, years later, were the inclusion of post-program support, outreach, and networking. If MAST wants to further develop its long-term impact on educators in MS, perhaps an online forum for teachers to share experiences and practices that work would yield greater confidence and support. Opportunities such as the MAST "mini conference" (lead by MAST alums for teachers) offers such experiences.

Final Conclusions and Discussion

The goal of this evaluation was to document what teachers experienced and learned as a result of participating in MAST. We sought to explore how they learned, as well as the various circumstances that helped shaped their learning. The outcome data reinforces the trends seen previously: MAST helps give teachers strategies and materials that they use in their classrooms in an effort to engage students in hands-on learning. Evaluation measures over a period of eight years included analyses of teacher attitudes towards science, student attitudes toward science, and teacher and student test results.

The results showed small to moderate statistically significant improvements among teachers in the following areas:

- Confidence in knowledge of all science subjects (e.g., chemistry, physics, astronomy, earth science);
- Confidence in ability to teach three out of four science subjects – all but astronomy;
- Confidence in using MAST pedagogical techniques (e.g., inquiry);
- Personal science teaching efficacy; and
- Science content knowledge.

Teachers also reported using MAST strategies for teaching inquiry and using MAST materials – evidence that MAST has influenced teachers' classroom practices. Analysis of teachers' written pre and post lesson plans showed that nearly all participating teachers made changes to their lesson as a result of participating in MAST. When observed in the classroom, most teachers' lessons were tied to Big Ideas covered in the MAST PD, and nearly all teachers integrated MAST activities, materials, and/or content into his/her lesson.

Collectively, student results showed gains in the following areas:

- Interest in chemistry and earth science;
- Physical science content knowledge for Alums only.

Project MAST's professional development model has shown success in producing some of its desired results thus far. We saw greater gains in Control Group students' scores, and we think we saw these gains because of MAST's impact, illustrating significant upward trends from pre-program and no MAST exposure to post-program and with MAST exposure.

Evaluation Limitations and Suggested Research Directions

There was one main limitation to our evaluations. Without extensive data on how teachers implement what they learn from MAST into their classrooms, it is difficult to attribute any reported changes in teacher knowledge, skills, professional practice, and student outcomes to the PD.

Uncovering how teachers re-enact what they learn from MAST may include asking all participants to plan and execute at least one "MAST lesson" during the academic year. This lesson should incorporate elements of MAST so that evaluators can compare and contrast these same elements to what was taught during the PD (e.g., use of materials from the PD, instructional techniques learned from the PD such as inquiry-based learning, etc.). This alignment between what is taught during the PD and what is executed in the classroom should and can be an essential focus in future research. Evaluators used lesson plans, observations and interviews to study how teachers replicated components of the PD during the "MAST lesson," but in limited capacity. In the future, evaluators might compare and contrast how MAST instructors represented inquiry-based learning during the PD versus how a teacher replicated that same strategy with his or her students. Comparing MAST lessons to non-MAST lessons can help explain the variations in lesson implementation, and illustrate ways in which teachers customize and adjust what is learned from the PD to better suit their students.

Additional Impacts - PD Instructors and observers and expansion of MAST model

The MAST PD instructors, many of whom have been teaching these courses for several years, are responsible for the following: (a) planning, developing and executing PD courses that are aligned with the Mississippi State Curriculum Framework and NGSS, (b) ensuring that lessons are executed successfully, and (c) to monitor and adjust the professional development program and experience from beginning to end based on teachers' learning levels. Seen as "the experts" in various science domains and pedagogical strategies, this role involves balancing the worlds of the teachers with those of their unique set of Common Core State Standards, while being knowledgeable of the elements inherent in each unique community. For the teacher, the PD instructor must weave together his or her own knowledge of the classroom, science content knowledge, and an understanding of how teachers learn, while helping teachers link the science they are learning to their own classroom teaching. Therefore, the evaluation begs the question, what do the MAST PD instructors take away from their experience, and how does their experience help inform and assess their own practice? In the upcoming evaluation, REA will incorporate the feedback of the MAST PD instructors to gather preliminary data on how their involvement in the program helped inform their curriculum and influence their own professional development. We will also further explore the extent to which instructors incorporated the feedback and suggested improvements voiced by participating teachers about MAST (e.g., content difficulty, content coverage) in an effort to create a more customized PD experience.

In addition to the PD instructors potentially benefiting from their involvement with the program, JSU faculty observers may have also reaped benefits. Since 2009, JSU faculty members from the Department of Physics, Atmospheric Sciences & Geoscience (PASG) were recruited to observe each PD session. These faculty members received ongoing training from REA before observations began. Current research claims that in pursuit of improving teaching practices, the best thing for teachers to do it to look outside of their own classrooms. According to Star and Strickland (2007), observing other teachers is a key element of development, and it improves teachers' own self-awareness of their skills and helps to identify areas for future growth. The future evaluation also begs the question, to what degree have the faculty observers' attitudes toward teaching science changed since being an observer? Also, to what extent have faculty observers implemented strategies and resources into their own classrooms by watching other teachers? REA will continue to explore how MAST has an impact on PD instructors and faculty observers. It is our belief that not only science teachers reap benefits from the program, but instructors and observers as well.

Final Thoughts

The MAST PD model moves beyond prior published work. First, unlike past studies, the main intervention is aligned with specific approaches associated with successful PD in the current literature, including a strong content focus, active learning (inquiry-based activities, student learning; coherence (alignment with the Mississippi State Standards); duration (graduate course credits); and collective participation (collaborative learning in school-based context) (Desimone, 2009; Garet, 2001). Additionally, the MAST PD model utilizes pedagogical strategies identified in science education literature that is considered effective for science K-12 instruction. Lastly, our previous study sought to determine if short-term PD gains and impact have staying power (> one year later) using self-reported data and, with our next study, outcome data. This eight-year evaluation has provided us with some answers about MAST's long-term impact and implementation, and has raised more questions we would like to explore with programs using the MAST professional development model.

References

Cooper, J. B. & Bass, K. M., Mushlin, S., Fadavi, M. (2011). Making it work: Cases of successful participants in a professional development program for high school science teachers. Paper presented at the annual meeting of the National Association for Research in Science Teaching (NARST), Orlando, FL, April 2011.

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. Educational Researcher, 38(3), 181-199.

Green, S. B., & Salkind, N. J. (2005). Using SPSS for Windows and Macintosh. Upper Saddle River, NJ: Pearson Education, Inc.

Meadows, G., Wiesenmayer, R. (1999). Identifying and addressing students' alternative conceptions of the causes of global warming: The need for cognitive conflict. Journal of Science Education and Technology. 8 (3), 235-259.

O'Donnell, C. L. (2008). Defining, conceptualizing, and measuring fidelity of implementation and its relationship to outcomes in K-12 curriculum intervention research. Review of Educational Research; 78(1), 33-84.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. Science Education, 66, 211-227.

Raudenbush, S. W., & Liu, X. (2000). Statistical power and optimal design for multisite randomized trials. Psychological Methods, 5, 199-213.

Riggs, I., & Enochs, L. (1990). Toward the development of an elementary teacher's science teaching efficacy belief instrument. Science Education, 74, 625-638.

Rockman et al (2012). Student and Teacher Responses to the MAST Planetarium and Podcast Lessons, 2009-2011. [National Science Foundation annual report]. San Francisco: Author.

Sadler, P., Coyle, H., Cook-Smith, N. & Miller, J. (2007). Misconceptions-oriented Standards-based Assessment Resources for Teachers (MOSART), Cambridge, MA: Harvard College. http://www.cfa.harvard.edu/smgphp/mosart/aboutmosart_2.html.

Sadler, P., Sonnert, G., Coyle, H., Cook-Smith, N. & Miller, J. (2013). The influence of teachers' knowledge on student learning in middle school physical science classrooms. American Educational Research Journal, 50(5), 1020-1049.

St. John. M. (2013). The MSP initiative – Documenting the total return on the federal investment. Session presented at the National Science Foundation's Math Science Partnership Learning Network Conference, Washington DC, February 2013.

Weiss, C. H. (1995). Nothing as practical as good theory: Exploring theory-based evaluation for comprehensive community initiatives for children and families. In J. P. Connell, A. C. Kubisch, L. B. Schorr, & C. H. Weiss (Eds.), New approaches to evaluating community initiatives: Concepts, methods, and contexts. Washington, DC: The Aspen Institute.