STEAM Go! A School District's Approach to Implementing New State Science, Technology & Engineering PreK-12 Curriculum Standards

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Abstract — **The purpose of this Trends in Engineering Education paper is to share research findings from one public school district that began an integrated, continuous STEAM (science, technology, engineering, art and mathematics) teacher professional development program in 2016 called *STEAM Go!* through the Center for STEM Education at Northeastern University in Boston. *STEAM Go!* brings timely and sustained professional development (PD) directly to teachers in their own schools and classrooms. Questions regarding the state's and districts' capacities to provide high quality [7] STEAM professional development to teachers led to several research questions:**

1. **Who will lead these initiatives if a district does not employ a specific STEM or STEAM district coordinator or administrator?**
2. **What practices and models might be implemented to ensure the needs of teachers and students are met?**
3. **What skills and expertise are essential for those identified to lead these efforts?**

***STEAM Go!* consisted of several full-day and half-day workshops at all 7 schools with 131 teachers responsible for teaching science plus follow-up correspondence, face-to-face visits, consultations, collaborative curriculum writing initiatives and model teaching events. As requested by the district, quantitative and qualitative surveys were administered to evaluate workshop quality and the PD provider's effectiveness. At the end of the year, another quantitative and qualitative survey was sent to all 104 elementary teachers who were responsible for teaching science to inquire about their curriculum development experiences during the school year and future PD needs. Research results indicate that elementary teachers in this district attempted to implement the new science units that their grade-level colleagues developed but not all teachers were able to teach all the lessons in the pilot year due to limited time and resources. Most of the elementary, middle school and high school teachers expressed a need to unpack the state's new STE standards in more detail with their colleagues in order to better understand new science and engineering content knowledge expected of them. All teachers unanimously agreed that they need more time to collaborate with their colleagues, more contemporary resources to assist them in delivering content, more time to develop inquiry-based learning (IBL), project-based learning (PBL), and engineering design lessons, and more incentives for taking on leadership roles. Teachers expressed an interest in continuous and sustained PD and curriculum development support from the PD provider. Based on the first formal year of implementing *STEAM Go!* the evidence points to a critical need for qualified and effective STEM and engineering education leadership across the state and the country.**

Index Terms—**engineering, professional development, STEM education, preK-12 teachers, Next Generation Science Standards.**

I. Introduction

IN 2016, Massachusetts adopted new science, technology and engineering (STE) standards for grades preK – 12 based on the new *Next Generation Science Standards* [1] and the National Research Council's 2012 *A Framework for K-12 Science Education* [2]. Science education specialists, policy makers and engineering educators have been working together to advance preK-12 STEM education in the United States in both formal and informal school settings for years [3], [4], [5], [6].

In the United States, technology and engineering were initially proposed as part of national science education standards starting in 1989 and then again in 1996 by the National Research Council. Some states, including Massachusetts in 2006, had already adopted technology and engineering standards into their middle and high school curricula before the Next Generation Science Standards (NGSS) were released. In fact in 1996, Massachusetts was the first state to establish K-12 standards for engineering education that were considered separate from science and technology [7]. More recently, the National Research Council (NRC) in 2012 published a conceptual framework for new K-12 science education standards that included engineering practices [2]. Prior to this landmark NRC publication, science education in the United States existed in its own silo, separate from engineering. As a result of the NRC *Framework for K-12 Science Education*, educators began to understand the benefit of integrating science and engineering together. Eventually, the National Science Teachers Association (NSTA) admitted that they had not been giving technology and engineering full credit in prior science education initiatives [8].

Despite a marked increase in the number of college graduates in the United States since 2001 (Fig. 1), the relative percentage of graduates pursuing engineering and other STEM (science, technology, engineering and mathematics) subjects compared to all college graduates has remained relatively constant, a trend that indicates that engineering, in particular, and other **STEM subjects are not growing in popularity** among college students in the United States [9].

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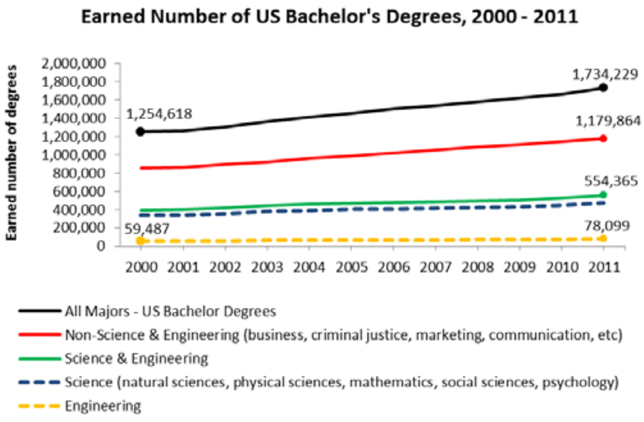

Fig. 1. Earned number of US Bachelor's Degrees, 2000 – 2011 (includes both domestic and international students). The dotted yellow and blue lines added together equal the solid green line. The solid green line plus the solid red line equal the solid black line [9].

Given such stagnant interest in STEM majors, it appears that our preK-12 STEM education system in the United States is not engaging enough students to pursue STEM fields, especially not in engineering.

Since Massachusetts was one of the leading states to help write the Next Generation Science Standards, it is no surprise that Massachusetts incorporated the NRC *Framework for K-12 Science Education* and the Next Generation Science Standards into its own new state standards [10]. To date, 38 states and the District of Columbia have either adopted the NGSS or developed their own standards based on recommendations from the NRC *Framework for K-12 Science Education* [11]. The key components of the new standards focus on science *and* engineering practices in that students should be able to demonstrate learning outcomes that integrate how scientists and engineers function in real-life to answer questions and solve problems. Specialized STEM professional development (PD) for all preK-12 teachers is therefore critical to ensure successful student outcomes.

Given that the existing elementary education system is structured so that most elementary teachers are individually responsible for teaching math, English Language Arts, science, and social studies with his/her own classroom of students, all elementary teachers will therefore need comprehensive and meaningful STEM professional development that provides them with STEM content knowledge and equitable STEM pedagogy strategies that benefit all students. In middle and high school, since teachers are hired as specialists in their field (either in science, social studies, mathematics, music, or English language arts, for example), middle school and high school science teachers also need comprehensive and meaningful STEM professional development that provides them with STEM content knowledge and STEM pedagogy strategies that benefit all of their students too.

A recent report published by Tufts University and the Education Development Center, a veteran professional development provider in Massachusetts, states that "There is a fundamental difference between the new framework and the older versions. For example, the newer framework calls attention to engineering design concepts as a critical facet of K-12 science and engineering education, and further defines design practices as an application of science and engineering" [7]. In this report, 45 stakeholders such as K-12 teachers, K-12 administrators, university and community college faculty and administrators, industry representatives, informal/out-of-school time educators and administrators, researchers, policymakers, funders and parents were interviewed and surveyed. 48% of respondents identified teacher professional development as an opportunity for collaboration. Respondents commented that the lack of teacher training is a challenge. According to the report, teachers feel that they "haven't had enough training in engineering education and do not feel confident about implementing it" [7]. In terms of comprehensive solutions, "districts are searching for these more comprehensive solutions (i.e., those that cover all or many of the grades and provide curriculum and professional development)" [7].

II. Theoretical Framework

Problem-based learning (PBL) "is a pedagogical approach and curriculum design methodology often used in higher education and K-12 settings" [12]. PBL "is driven by challenging, open-ended problems with no one 'right' answer". "Students are faced with contextualized, ill-structured problems and are asked to investigate and discover meaningful solutions" [12]. This is indeed the case when STEM lessons are used to reflect on real-world scenarios: open-ended and ill-defined problems with the potential for several solutions, not just one right answer.

Project-based learning (also PBL) can be described as any project that endures for several days, weeks or months and is characterized by students actually doing a project, perhaps within a real-life context. The Boston Museum of Science's Engineering is Elementary's curriculum is grounded in problem-based and project-based learning, which research has shown has been especially effective in improving student learning of science concepts as they relate to engineering [13].

Inquiry-based learning (IBL) is "an approach to learning that involves a process of exploring the natural or material world, and that leads to asking questions, making discoveries, and rigorously testing those discoveries in the search for new understanding. Inquiry, as it relates to science education, should mirror as closely as possible the enterprise of doing real science. The inquiry process is driven by one's own curiosity, wonder, interest or passion to understand an observation or solve a problem" [14].

Bruner's 9 tenets of education [15] and his discovery learning theory [12] are also applicable to STEM education. In particular, tenets that involve constructivism and interaction are the most relevant to students who make their own meaning of what they are learning by doing the STEM projects on their own, especially in team settings. "Discovery learning is an inquiry-based, constructivist learning theory that takes place in problem solving situations where the learner draws on his or her own past experience and existing knowledge to discover facts and relationships and new truths to be learned" [12]. John Dewey's writings [16] about experiential education also support discovery learning, problem-based learning and project-based learning and therefore, STEM and engineering education in particular.

Since "the methods teachers use to teach science to young people clearly have an effect on how students perceive the subject", science pedagogy that over-emphasizes rote learning should be avoided [17]. This suggests that project-based learning, inquiry-based learning and other 21st century approaches to STEM pedagogy should be implemented instead.

The problem is that most teachers, especially in elementary school settings, are not prepared to teach integrated STEM subjects using either problem-based, project-based, experiential or discovery learning strategies. Their backgrounds may not have been in a STEM area. Even if they did major in a STEM discipline, which most elementary teachers do not, they may not be practicing that discipline in their primary teaching appointment. They also may not have learned how to teach integrated subjects effectively as this practice is relatively new in education. Therefore, teachers need high quality, effective, comprehensive, convenient, affordable, customized, embedded, and continuous STEM professional development that fits their schedules, their budgets and their professional goals, including the needs of their districts, schools and students.

III. Professional Development Best Practices

Laura Desimone argued in her seminal paper that there is finally enough empirical research to identify effective professional development characteristics and a core conceptual framework for studying the effects of professional development [18]. These characteristics include content focus, active learning, coherence (how teacher learning is consistent with teachers' knowledge and beliefs), duration and collective participation (for example, professional learning communities). Desimone's conceptual framework starts with these PD characteristics and then progresses to teacher change, instructional change and then improved student learning. After an exhaustive review of the research on how to accurately measure the effects of PD on teacher learning, change and classroom practice, Desimone identified observation, interviews and surveys as well-established instruments in professional development.

Guskey and Yoon reviewed over 1,300 studies on whether teacher professional development in reading, language arts, math and science had any direct impact on student learning outcomes [19]. The authors found that only 9 out of the 1,343 reviewed studies provided credible evidence that met standards established by the What Works Clearinghouse, a division of the United States Department of Education that is responsible for scientific evidence to support "what works" in education. They concluded that the following characteristics of effective PD are directly linked to student achievement: workshops, outside experts, follow-up, activities, and content. The fact that they explicitly mention outside experts is another piece of evidence toward identifying the leaders involved in STEM professional development and their role in the initiative, and thus addressing Research Question 1.

A list (Table 1) of effective research-based characteristics of professional development from 12 National Science Foundation Graduate STEM Fellows in K-12 Education programs identified several key components [20]. This paper relies on a well-known and widely accepted science and mathematics professional development model published by Susan Loucks-Horsely, *et al*. [21].

TABLE I
EFFECTIVE CHARACTERISTICS OF STEM PROFESSIONAL DEVELOPMENT [20].

1. Teachers' discipline specific knowledge is increased.
2. Teachers understand how students learn and what effective teaching strategies are within a specific discipline.
3. Teacher effectiveness and student achievement outcomes are used to determine whether PD has worked.
4. Requires resources (money & time).
5. PD is on-going.
6. PD occurs in the day-to-day contexts of teachers.
7. Uses effective teaching strategies.
8. PD must be coherent and aligned with school/district/state goals.
9. Teachers should provide input into PD design: PD is engaging and relevant.
10. Involves collaboration between teachers and others.
11. Generates further collaboration or projects.
12. Treats teachers as professionals.
13. Promotes teacher self-reflection.
14. Uses inquiry as a teaching style.
15. Increases teacher ability to meet the needs of diverse learners.

According to Christine M. Cunningham, the founder and director of the pioneer Engineering is Elementary program at the Boston Museum of Science, the following components are important to K-12 teacher professional development in STEM subjects, especially in engineering [22]:

1. Engage teachers in engineering practices.
2. Model pedagogies that support those practices.
3. Give teachers experiences as both learners and teachers.
4. Develop teachers' understanding of the fundamentals of and interconnections between science and engineering.
5. Help teachers to understand engineering as a social practice.

With the Next Generation Science Standards and an increasing emphasis on professional development in engineering, veteran ASEE researchers recognized a need to establish professional development *standards* for teachers of engineering to help steer PD providers toward high-quality engineering professional development practices [23]. In their study, they reviewed the professional development literature and research about adult learning to inform their development of standards for how to design effective professional development for teachers of engineering. Their objective was to provide a qualitative framework of PD design that can help design, improve and select PD experiences that effectively equip in-service teachers to improve their practice as teachers of engineering. The American Society for Engineering Education (which works with the National Science Teachers Association) enthusiastically endorses this qualitative framework:

1. PD for teachers of engineering should address the fundamental nature, content and practices of engineering to promote engineering content knowledge.

2. PD for teachers of engineering should emphasize engineering pedagogical content knowledge.
3. PD for teachers of engineering should make clear how engineering design and problem solving offer a context for teaching standards of learning in science, mathematics, language arts, reading and other subjects.
4. PD for teachers of engineering should empower teachers to identify appropriate curriculum, instructional materials and assessment methods.
5. PD for teachers of engineering should be aligned to current educational research and student learning standards.

STEAM Go! was designed with this framework in mind.

IV. Professional Development Leadership

In a PD leadership study, 262 K-12 teachers completed several surveys before and after a summer integrated STEM professional development institute [24]. One particularly relevant question about the participants' personal experiences with STEM education leadership in their communities found that 54% of participants said no leaders "to my knowledge" existed for them, which means these teachers were engaging in STEM professional development without any leadership supports in place. 26% of participants said that there is one teacher-leader in the building that hasn't changed in several years (a 4th or 5th grade teacher, for example), while 12% said that STEM leadership in their community is vague. Only 6% of the participants said that they have STEM coordinators in their community. This lack of STEM leadership supports the scholarly significance of this research problem in that there are documented voids to fill with respect to the actual people who will lead teachers and their schools through implementing new curriculum standards in STEM education. *STEAM Go!* attempts to address this void in engineering education practice.

Another recent study identified district leaders as critical components in science education [25]. In their literature review, Whitworth and Chiu point out that "relatively few studies connect the role of leaders who plan and implement professional development to teacher change" [25] and therefore student achievement. After an exhaustive review of the literature regarding the proven elements of professional development that lead to teacher change and improved student achievements, the authors address how district leadership and teacher leadership can positively influence professional development activities. Specifically, "district leadership encompasses the roles of staff developers, subject-area supervisors, district coordinators, mentor teachers, school-board members, directors and community members, but is most often focused on the role of the superintendent" [25]. Their study directly addresses the components of successful professional development and the idea that subject-area coordinators such as science coordinators should be directly involved with choosing professional development initiatives for their teachers and participating in professional learning communities themselves.

In summary, the research is very clear that STEM professional development for teachers, especially in engineering and science, is beneficial to teachers, their students, their districts and their education programs and that local leadership in this area is scarce.

V. Methods

During the summer of 2016, an engineering faculty member, who was already familiar to a particular Massachusetts school district for prior volunteer work in the schools' STEAM Labs, was approached by the district's superintendent's office to design, deliver, implement and support continuous science professional development (PD) for the upcoming academic year as part of the engineering faculty member's doctorate in education dissertation work. Plans focused on the new state STE standards, aligning the district's science curriculum, and pedagogical needs including inquiry-based and project-based teaching and learning. This district is a suburban medium-sized public school district with approximately 4,200 students in grades preK-12 and 325 full-time educators. The district includes 1 high school (grades 9 – 12), 1 middle school (grades 6 – 8) and 5 elementary schools (3 schools grades K – 5 and 2 schools grades preK – 5). Of the total 131 district teachers who are directly responsible for teaching science, there are 104 elementary, 11 middle school and 16 high school science teachers. Other teachers who are responsible for teaching math, computer programming and engineering at both the middle school and high school levels were not part of this pilot initiative.

Fig. 2. Inquiry-based learning model [27].

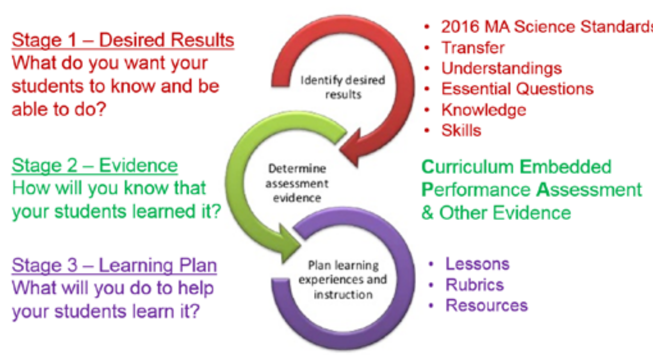

Fig. 3. Backwards Design curriculum planning framework [26].

STEAM Go! consisted of 10 full-day workshops and 1 half-day workshop with 16 high school, 11 middle school and 98 elementary teachers (including preschool teachers) between October 2016 and June 2017. The content of each workshop included: inquiry-based learning (Fig. 2), project-based learning, Curriculum Embedded Performance Assessments (CEPAs), backward design principles in curriculum writing [26] (Fig. 3), concept maps (Fig. 4), and each grade level's new Massachusetts science / technology / engineering curriculum standards [10], which covers earth science, life science, physical science and engineering design.

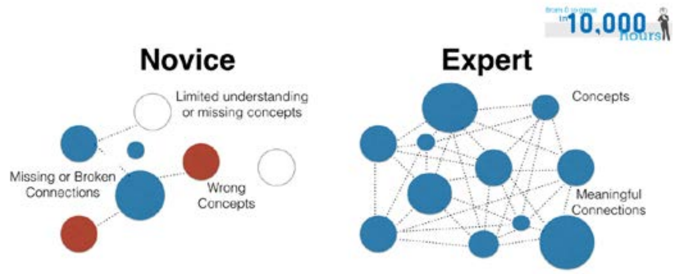

Fig. 4. Concept maps and how learning works [28].

As part of a district-wide initiative, teachers were expected to develop new science curriculum in grade-level teams using backward design and a 3 year rollout plan designed by the Assistant Superintendent and a committee of district teachers. Teachers who volunteered for the elementary science committee had received some prior Understanding by Design [26] training for an initial new science unit the year before. Teachers were informed that the PD provider would be working with them all year to develop, design, write and pilot new science curriculum that aligns with the new STE curriculum standards. Since there are 5 elementary schools in the district, an elementary science committee was formed to lead curriculum development by grade level. All teachers were invited to request 1-on-1 help from the PD provider to identify inquiry-based activities and resources, to develop and design new science curriculum units, and to even pilot teach a new unit in the classroom with the PD provider's help, especially for any engineering design lessons.

Additional follow-up correspondence, additional full-day and half-day PD workshops, face-to-face visits, consultations, collaborative curriculum writing initiatives and model teaching events were facilitated by the PD provider throughout the school year as needed and as requested by either the Assistant Superintendent, high school science department head, middle school science coordinator, elementary science committee chair, or the teachers themselves.

A total of 62 actual contact hours were invested by the PD provider, not including preparation, planning, email correspondence, and 1-on-1 follow-up visits with teachers. Elementary teachers responsible for teaching science each spent about 1.5 workshop hours with the PD provider, middle school science teachers each spent about 6 workshop hours and high school science teachers each spent about 12 workshop hours with the PD provider. Additional time with each teacher varied according to teachers' needs (from 0 hours – 6 additional hours) throughout the school year.

As requested by the district, one (1) quantitative and qualitative online survey was anonymously administered to all teachers after each initial PD workshop to evaluate the quality of the PD workshop and the effectiveness of the PD provider. 10 out of 16 high school, 8 out of 11 middle school, and 63 out of 98 elementary teachers completed the initial survey. At the end of the academic year, another quantitative and qualitative online survey was sent to all 104 elementary teachers who were responsible for teaching science to inquire about the teachers' yearly progress toward teaching the new science unit designed by their grade-level colleagues on the elementary science committee. 35 elementary teachers completed this survey to anonymously document their experiences with inquiry-based learning and their professional development needs and classroom resource needs for the upcoming years. Copies of both surveys are included in the Appendix.

VI. Results

On a 5-point Likert scale (strongly agree, slightly agree, neither agree nor disagree, slightly disagree, strongly disagree), the majority of high school, middle school and elementary school survey respondents agreed that the PD provider was well-prepared, knowledgeable and effective in facilitating the initial full-day or half-day workshop on inquiry based learning, curriculum embedded performance assessments (CEPAs) and the new state STE curriculum standards. CEPAs are student assessments that the Massachusetts Department of Elementary and Secondary Education supports in its backward design approach to curriculum planning and writing [26].

On a 5-point Likert scale (strongly agree, slightly agree, neither agree nor disagree, slightly disagree, strongly disagree), most high school, middle school and elementary school survey respondents agreed that the PD workshops fulfilled the day's learning objectives and covered pedagogical content knowledge with respect to inquiry-based learning and CEPAs. At this point in the initial stages of the PD program, teachers only had about 3 contact hours with the PD provider and had not yet explored actual examples of inquiry-based lessons and CEPAs in their own curriculum.

In the open comments section of the first survey, all survey respondents commented that the workshop with their colleagues was engaging and that they learned valuable information about the differentiated kinds of inquiry-based learning, which improved their confidence in using inquiry-based learning in their classrooms. However, they also expressed concern about district leadership's expectations and whether they would be able to implement new pedagogical strategies such as inquiry-based learning and CEPAs in order to cover the new standards if only standardized testing would be used to assess their performance. Teachers suggested that their district leadership team create more time outside of the normal school day for additional opportunities to collaborate, brainstorm and explore more creative curriculum units and lesson plans. They expressed an interest in more PD and curriculum development support from the PD provider.

At the end of the school year in the second survey, a diverse representation of 35 elementary teachers (Fig. 5) responded that they were more successful implementing the lesson plans in the new science units compared to the new CEPAs (Fig. 6). Their reasons included lack of time, lack of resources, and unfamiliarity with the new science standards, CEPA requirements and CEPA assessments. Teachers also indicated that they would appreciate the opportunity to improve their new science curriculum units after piloting them the first year.

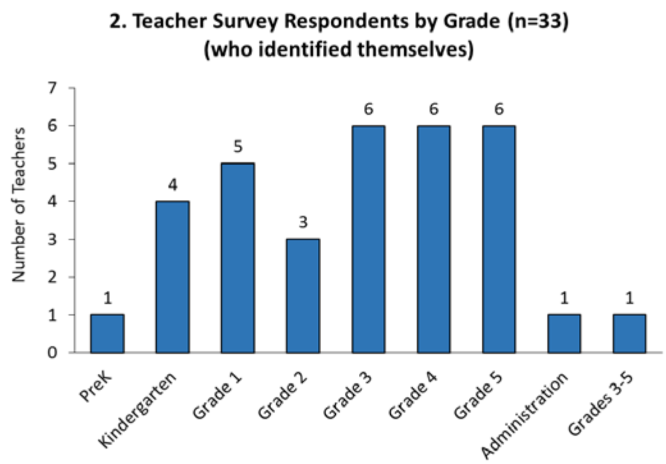

Fig. 5. Demographics from end-of-year online survey responses for grade level affiliations for elementary teachers (n=33).

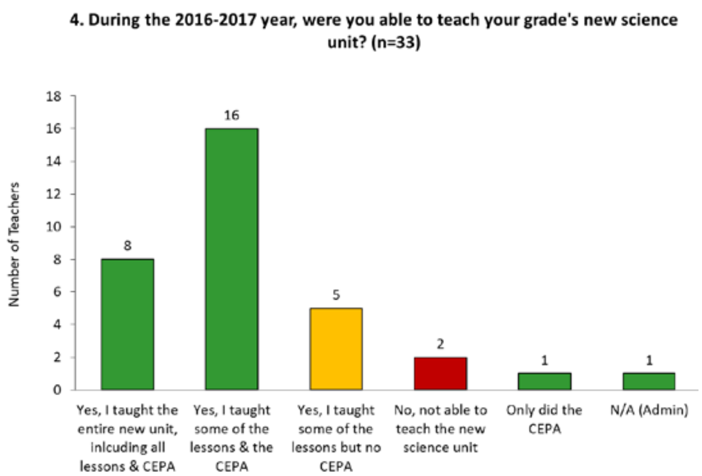

Fig. 6. End-of-year online survey responses for new science unit implementation for elementary teachers (n=33).

Elementary teachers also overwhelmingly supported the use of Mystery Science (www.mysteryscience.com) in their new science curriculum, which is currently being paid for by each elementary school or by a locally funded education foundation grant. Interestingly, one elementary teacher suggested that each school consider hiring its own full-time STEM specialist, in a position similar to the art, music, instructional technology, and librarian specialists, to better address the state's new approach to integrated STE education (Fig. 7). This suggestion helps address this study's first research question: who will lead these initiatives if a district does not employ a specific STEM or STEAM district coordinator or administrator?

Also gathered from observations and personal notes, most of the elementary, middle school and high school teachers expressed a need to unpack the state's new STE standards in more detail with their colleagues in order to better understand the directed content that they would be expected to cover. This is understandable considering that the standards were only just recently adopted in 2016. In addition to new topic areas, many of the topics in the new state STE standards shift up or down a grade level in elementary school, compared to the previous standard. Consequently, elementary teachers expressed a desire to acquire curriculum resources from teachers in other grade levels and from external sources such as educational websites, non-profit organizations and other educators and programs. Regardless of background, years of science teaching experience or grade level, teachers in this district unanimously agreed that they need more time to collaborate with their colleagues, more contemporary resources to assist them in delivering content, more time to develop inquiry-based and project-based units and lessons, and more incentives for taking on leadership roles in designing and developing the new curriculum, especially if they volunteer to serve on a curriculum committee.

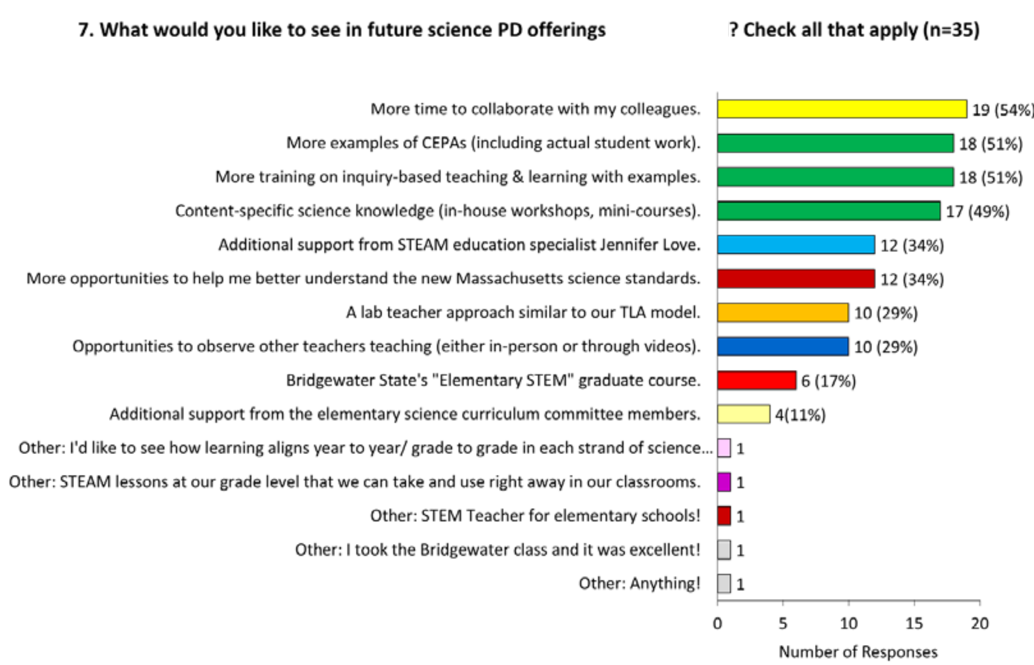

Fig. 7. End-of-year online survey responses for future science PD needs for elementary teachers (n=35).

VII. Discussion

Three research questions were answered by exploring qualitative and quantitative survey results from one district:

1. Who will lead these initiatives if a district does not employ a specific STEM or STEAM district coordinator or administrator?

Based on the analysis, it appears that this school district relies on its individual teachers to take leadership roles among themselves to design, develop and implement new science curriculum, under the leadership of their Assistant Superintendent. Although there is a middle school science coordinator (who also teaches full-time) and a high school science department head (who teaches a lighter course load), there is no science coordinator at the elementary level or a district-wide science coordinator to manage this critical curriculum initiative across all 7 schools and all preK-12 grade levels. As is the case for most public school districts, the Assistant Superintendent is ultimately responsible for all curriculum, including math, science, social studies, English Language Arts, computer science, technology education, art, music, physical education, etc..

The PD provider in this study was able to support the Assistant Superintendent and, more importantly, the teachers directly in their own schools and classrooms, hence the name *STEAM Go!*. The PD provider was able to fill a critical vacancy in science curriculum leadership, particularly among the elementary teachers, in terms of content knowledge (the new science, technology & engineering standards), pedagogical content knowledge (inquiry-based learning, project-based learning and engineering design), and identifying accessible and high quality curriculum resources in STEM education. Local experts could also be involved as leaders, especially to support authentic, place-based curriculum with connections to the community, and many teachers and school already leverage these resources (life science and garden curriculum through Holly Hill Farm in Cohasset, MA, for example).

Based on observations and survey responses, several teachers at the different schools indicated that they take on considerable leadership responsibilities to design, develop and implement new science curricula, especially if they participated on the elementary science committee or serve as veteran teachers in their schools. Committee member teachers at the elementary level may have educational backgrounds in science or developed science interests and are therefore more comfortable teaching science. Regardless of grade level, many teachers expressed a need for additional incentives to continue in these informal leadership roles and for additional coordination efforts across all schools, to both horizontally and vertically align the district's new curriculum to the new science standards.

The science coordinator and department head at the middle school and the high school, respectively, meet regularly with their teachers throughout the school year, but feedback from their teachers' initial PD workshop surveys indicates that they are also looking for additional leadership and guidance from the district to both horizontally and vertically align their new science curricula with the lower grade levels.

2. What practices and models might be implemented to ensure the needs of teachers and students are met?

Since this PD initiative was designed with prior knowledge of professional development best practices, several practices and models are <u>definitely recommended</u> for others interested in implementing similar PD models and for additional STEAM PD in this district to meet the needs of teachers and their students:

1. Engage teachers in only 1 major curriculum initiative at a time, or understand that other concurrent district-wide curriculum initiatives can be overwhelming for teachers to implement at the same time.

2. Plan more time for teachers to collaborate with their colleagues, either each week, each month or at regular intervals during the school year. Offer additional paid time outside of normal school hours during the summer, if needed, or when permitted by teachers' contracts.

3. Provide teachers with more time to develop IBL, PBL and engineering design lessons and to pilot and assess them as collaborative teams.

4. Provide teachers with more contemporary resources to assist them in delivering modern science, technology and engineering content. Resources may include online educational materials, inquiry-based experiments, problem-based projects, and access to community STEM resources and experts including the Boston Museum of Science, the New England Aquarium, the South Shore Science Center, Holly Hill Farm in Cohasset, the North and South River Watershed Association, and nearby universities including Northeastern University and Bridgewater State University.

5. Provide teachers with continuous, accessible, embedded and sustainable professional development and curriculum development support after the initial workshop. Teachers need to feel that they have partners and a "coach" in the new curriculum initiative so that they don't feel isolated or abandoned. This is one of *STEAM Go!'s* highest priority. PD providers, other teacher leaders, principals and administrators can all serve in support roles, but they should be willing to embed themselves into a sustained long-term curriculum writing initiative alongside the teachers.

6. Schedule science PD workshops and meetings at the teachers' schools where they are more conveniently available together, as opposed to scheduling PD off-site. *STEAM Go!* made this a priority.

7. Invest in qualified substitute teachers to cover elementary teachers' classrooms for multiple ½ day or full-day PD workshops and curriculum writing sessions throughout the year.

8. Some middle school and high school science teachers may not appreciate missing valuable instructional time with their own students to work on science curriculum during the school day. Therefore, they may prefer to work on science curriculum at other times.

9. Implement creative ways for teachers to visit each others' classrooms to observe new science, technology and engineering lessons and innovative teaching strategies (for example, "pineapple charts" https://www.cultofpedagogy.com/pineapple-charts).
10. Enlist the help of each district's middle school and high school science teachers, especially any science coordinators or department heads, to share content knowledge with their elementary teachers. For example, during the summer of 2017, the high school science department head (who is also a biology teacher) engaged the elementary science committee members in a 2 hour "boot camp" on life science. The elementary teachers appreciated this new knowledge and the opportunity to engage with an accessible teacher and life sciences expert in their own district. This strategy supports vertical alignment from "top to bottom" and could also be used "bottom to top".
11. Develop teachers' understanding of the fundamentals of and interconnections between science and engineering [22].
12. Engage teachers in science and engineering practices and model pedagogies that support those practices [22].

3. What skills and expertise are essential for those identified to lead these efforts?

Based on answers to the first research question regarding leadership, teachers, administrators, professional development providers and local experts will undoubtedly need specific science, technology and engineering content knowledge and pedagogical knowledge to help lead new science curriculum efforts. Expertise in engineering design and engineering education is particularly helpful as most teachers do not have backgrounds in engineering practices and how these practices connect to science, technology, art and mathematics. Leaders should also be responsive to teachers' immediate pedagogical needs and to the diverse needs of their students. These leaders should be able to build a collaborative community of teachers who value contemporary STEM education, invest in their own professional development as 21st century teachers and who believe that ALL students are capable of engaging in authentic science and engineering practices. These leaders should also be knowledgeable about the STEM industry and institutions of higher education in order to support students' future career and educational goals and opportunities, especially for students who are under-represented in STEM fields.

VIII. Conclusion

Within the last few decades, professional development for in-service STEM teachers has mostly focused on science. However, as more states, districts and schools incorporate the new Next Generation Science Standards or components of the NRC's *Framework for K-12 Science Education* into their own science and engineering curriculum standards, the need for continuous and sustained curriculum development support from qualified PD providers, STEM coordinators, administrators and teacher leaders is at a critical crossroad. This paper highlights the specific needs and experiences of elementary, middle school and high school teachers in a particular district that have been supported by a STEM education partner in higher education. This research is important to engineering education in general because it identifies practices, models and specific expertise that will be needed to foster and embrace STEM educators and their students at the primary and secondary education levels in the United States, which subsequently influences the quality and quantity of college students enrolled in STEM majors. Additional work is already underway for academic year 2017 – 2018 to continue supporting teachers and administrators in this and other Massachusetts' districts.

Appendix

Both survey instruments used in this study can be found after the References section for clarity reasons.

Acknowledgment

J. Love thanks the Marshfield Public School District for initiating this partnership, Marshfield's teachers and administrators who participated in the PD workshops and provided valuable feedback through surveys and conversations, Northeastern University's Center for STEM Education for helping design *STEAM Go!* STEM teacher professional development, and the numerous faculty in Northeastern University's College of Engineering and Graduate School of Education for inspiring her to pursue a doctorate in education in support of accessible preK-20 STEM education for all students.

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Appendix: Initial Online Anonymous Professional Development Workshop Survey
(sent to all 16 high school, 11 middle school and 98 elementary teachers between October 2016 – April 2017).

Thank you for taking a few minutes to complete this survey. Your responses will be submitted anonymously when you click on "Done" at the bottom of the page. You may go back and revise your responses at any time by using the same device and the same web browser.

1. Which session did you attend on Friday, October 21, 2016 at ?

- [ ] Morning 7:15am - 10:26am (Biology)
- [ ] Afternoon 11:00am - 1:47pm (Physics & Chemistry)

This question was customized for each initial PD workshop for each of the 7 district schools.

2. Please rate the following based on your session experience:

	Strongly Agree	Slightly Agree	Neither Agree Nor Disagree	Slightly Disagree	Strongly Disagree
I learned more about inquiry-based learning than I had originally expected.	○	○	○	○	○
I learned why inquiry-based learning is important to my students' development.	○	○	○	○	○
I learned how to implement inquiry-based learning into my own teaching practice.	○	○	○	○	○
I am now more confident in my ability to implement inquiry-based learning into my own teaching practice.	○	○	○	○	○
I learned more about Curriculum Embedded Performance Assessments (CEPAs) than I had originally expected.	○	○	○	○	○
I learned more about what components contribute to a well-designed CEPA.	○	○	○	○	○
I learned how to implement alternative assessments (concept maps, K-8 outreach projects, informal surveys, personal reflections) into my own teaching practice.	○	○	○	○	○
I am now more confident in my ability to develop Curriculum Embedded Performance Assessments (CEPAs) with my colleagues for our curriculum.	○	○	○	○	○
I plan to apply new knowledge about inquiry-based learning and CEPAs toward my own professional practice as an educator in the near future.	○	○	○	○	○

3. Please rate the professional development provider (Jennifer Love) based on your experience:

	Strongly Agree	Slightly Agree	Neither Agree Nor Disagree	Slightly Disagree	Strongly Disagree
The PD provider was well prepared to meet the session's established goals.	○	○	○	○	○
The PD provider was knowledgeable about the topics covered.	○	○	○	○	○
The PD provider was effective in engaging participants, sharing useful tools and facilitating the discussion.	○	○	○	○	○
The PD provider identified, shared and illustrated enough examples of inquiry-based lessons, units and CEPAs to help me envision inquiry-based learning in my classroom.	○	○	○	○	○

4. Please share any **general comments** about Friday's professional development session (strengths and/or weaknesses).

5. Please identify any **useful "take-aways"** from Friday's session that will be helpful to you in your teaching.

6. Please share any **questions or concerns** that you have about inquiry-based learning and/or CEPAs.

7. What else do you need to support you (and your colleagues) in implementing higher levels of inquiry-based learning into your teaching?

8. What else do you need to support you (and your colleagues) in developing and writing CEPAs for your curriculum?

Thank you for completing this survey to help the support you in the important work you do for our students and our community.

Done ▸

Elementary Science Teacher Survey

This is a quick (5-minute) survey about this year's revised science curriculum initiative for all elementary teachers who teach science. Your responses will help our district and school leadership teams support you, your colleagues and your students. Thank you!

1. Which school(s) or program(s) are you currently affiliated with? Check all that apply.

- [ ] school names have been hidden for confidentiality
- [ ]
- [ ]
- [ ]
- [ ]
- [ ] Early Childhood Program
- [ ] Other:

2. During academic year 2016-2017, in which primary grade level(s) did you teach science?

- [ ] PreK
- [ ] Kindergarten

- [ ] Grade 1
- [ ] Grade 2
- [ ] Grade 3
- [ ] Grade 4
- [ ] Grade 5
- [ ] Other:

3. Were you a member of the elementary science curriculum committee this year?

- ( ) Yes
- ( ) No

4. During academic year 2016-2017, were you able to teach your grade's new science unit?

- ( ) Yes, I taught the entire new unit, including all lessons and the CEPA.
- ( ) Yes, I taught some lessons of the new science unit and the CEPA

- Yes, I taught some lessons of the new science unit and the CEPA.
- Yes, I taught some of the lessons but no CEPA.
- No, I was not able to teach the new science unit.
- Other:

4a. If you were able to teach your grade's new science unit, which one did you teach and in what capacity?

Your answer

4b. If you did not teach your grade's new science unit this year, why?

Your answer

5a. How would you rate the overall quality of the LESSONS in your grade's new science unit?

- Poor (not engaging, not inquiry-based, needs more development to support the standards).
- Fair (somewhat engaging and inquiry-based but does support the

- Fair (somewhat engaging and inquiry based but does support the new standards).
- Good (engaging, somewhat inquiry-based, meets the new standards).
- Excellent (very engaging, definitely inquiry-based and definitely meets the new standards).

5b. How would you rate the overall quality of the CEPA in your grade's new science unit?

- Poor assessment of student's knowledge.
- Fair assessment of student's knowledge.
- Good assessment of student's knowledge.
- Excellent assessment of student's knowledge.

5c. What changes or improvements, if any, do you think should be made to your grade's new science unit, including any of the lessons or the CEPA?

Your answer

6a. How often did you actively use Mystery Science in your classroom this year?

- 3-5+ times.
- 1-2 times.

- Looked at it but did not use it with students.
- Heard about it but did not look into it.
- What's Mystery Science?
- Other:

6b. How effective are Mystery Science lessons and "mysteries" in helping you teach science?

- Extremely Effective (Mystery Science delivers accurate & unique content in an engaging way).
- Slightly Effective (Mystery Science is great but I can find free duplicate content elsewhere).
- Neither Effective or Ineffective (no opinion).
- Slightly Ineffective (Mystery Science is not relevant to my lessons and distracting to my students).
- Extremely Ineffective (Mystery Science does not meet my teaching needs).
- I'm not sure (I've never seen or used Mystery Science).
- Other:

6c. Would you be interested in using Mystery Science in the future?

- Yes! However, my free subscription will expire during the 2017-2018 year.
- Yes! I will sign up for a free subscription for the 2017-2018 year

- ◯ Yes! I will sign up for a free subscription for the 2017-2018 year.
- ◯ Yes but I'd like to explore it first and/or talk to my colleagues.
- ◯ No, I'm not interested.
- ◯ Other:

7. What would you like to see in future science PD offerings in ? Check all that apply.

- ☐ content-specific science knowledge (in-house workshops, mini-courses).

- [ ] more training on inquiry-based teaching & learning with examples.
- [ ] more time to collaborate with my colleagues.
- [ ] opportunities to observe other teachers teaching (either in-person or through videos).
- [ ] a lab teacher approach similar to our TLA model.
- [ ] Bridgewater State's "Elementary STEM" graduate course.
- [ ] more examples of CEPAs (including actual student work).
- [ ] more opportunities to help me better understand the new Massachusetts science standards.
- [ ] additional support from the elementary science curriculum committee members.
- [ ] additional support from STEAM education specialist Jennifer Love.
- [ ] Other:

8. What else can you share about your science teaching experience(s) this year (positive or negative) and how the elementary science curriculum committee can better support your needs and those of your students?

Your answer