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A Three-Year Model for Building a Sustainable Science Outreach and Teacher Collaborative

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ABSTRACT: BioEYES is a K-12 science outreach program that develops self-sustaining teachers as a replication strategy to address high demand for the program while promoting long-term school partnerships. This paper explores the practices of "model teachers" from multiple grades, who are empowered over a three-year period to deliver BioEYES' hands-on science content autonomously, as compared to the program's standard co-teaching model (BioEYES educator + classroom teacher). The authors found that BioEYES' professional development (PD) workshop, classroom co-teaching experience, and refresher trainings assist teachers in gaining autonomy to teach the program's curricula. In addition, the authors found: 1) a similar effectiveness on student learning across three grade bands, and 2) positive attitude changes about science as a result of the program, regardless if the BioEYES unit was taught by a model teacher or program staff. Further we found that high school model teachers exceeded the performance of BioEYES educators. This observation supports our contention that giving high quality STEM programing that includes multi-level PD to teachers generates the strongest possible outcome. Overall, we characterize the impact and financial investment of BioEYES and describe a PD framework that can be used by outreach providers to deliver content, expand their reach, and sustain school partnerships.

INTRODUCTION

Over many decades, numerous national reports noted the need for reform in science, technology, engineering, and math (STEM) education (National Academy of Sciences, 2007; National Academies of Sciences, Engineering, and Medicine, 2018; U.S. Department of Education, 1984, 2000). Such reports advocated for changes in curricula and improvements in teacher preparedness. While the U.S. needs qualified STEM professionals, it is no secret that its students lag in science assessments when compared to international cohorts. In the Philadelphia and Baltimore public school districts, two areas where BioEYES (described below) has a large presence, teachers and their students face systemic challenges. These students simply don't have the resources to achieve in science when measured by state assessments. In the School District of Philadelphia, 79% of 8th graders and 70% of high schoolers scored basic or below basic on the state science assessment (School District of Philadelphia, 2017a). In 2016, 71% of Baltimore City Public Schools 8th graders and 41% of high schoolers scored basic or below on the Maryland School Assessment in science (Maryland State Department of Education, 2016). Under President Trump's five-year STEM strategic plan, diversity in the workforce and access are again common themes, however, it is projected that only $200 million dollars per year are budgeted (U.S. Office of Science and Technology Policy, 2018). In contrast, former President Obama allocated $3 billion dollars in 2016 (Handelsman and Smith, 2016). In sum, the need for outreach organizations to implement strategies that will help sustain their STEM education efforts during these tough financial times is even more critical.

To address these challenges, Project BioEYES (www.bioeyes.org), a community- and evidence-based, K-12 life science outreach program, was created in 2002 by two of the paper's authors, Drs. Shuda and Farber (Shuda, et al., 2016). The curriculum focuses on embryology, animal development, and genetics using live zebrafish.

The BioEYES program has been replicated in multiple locations and forms. While BioEYES has been adopted by a number of global education partners including universities, science institutions, for-profit corporations, education nonprofits, BioBuses, scientific societies, and in individual schools, at its core each BioEYES site is largely associated with an academic research institution that partners with local schools and independently funds its operations. First, universities are in a better position to leverage existing resources and staff capacity to provide: a) teacher professional development to multiple participants, and b) subsequent co-teaching and program delivery in the classroom. Second, teachers typically don't have revenue for travel to attend an in-house training at one of our locations. Third, we have not yet developed the materials needed (e.g., webinars, online courses, etc.) to support training teachers remotely. And lastly, BioEYES has limited staff capacity and time available to dedicate to program replications, and so maximizing our efficiency is essential.

BioEYES trains our replication partners, primarily university faculty and staff and local teachers selected for the pilot, on the curriculum, pedagogy, and teacher PD. This ensures program fidelity. However, there is flexibility in how the program is delivered and implemented, and on the size of the effort. Williams College provides an interesting example. There, a faculty member offers a 3-week intersession course to undergraduates where students learn the BioEYES curriculum and practice a mock delivery at the college, followed by one week of program delivery in a local school. After ten years, Williams College has expanded their effort to include eight schools. Other models have involved partnerships with scientific society members that serve as Outreach Educators and teacher trainers. Or sending BioEYES Model Teachers to China to deliver curriculum at a for-profit education institution. The replications are a balance between adapting to a partner's needs and capacity, and ensuring the program maintains reasonable program fidelity.

As is true for many self-funded programs that achieve success, the fiscal challenges and the programmatic demand from teachers, school districts, and others cause an organizational strain but also created an enterprising opportunity for BioEYES to develop "Model Teachers," referred to as MTs. BioEYES MTs are trained K-12 classroom teachers that deliver the BioEYES curricula autonomously after 2–3 years of co-teaching with BioEYES staff, with program materials loaned by BioEYES staff. Given that there are a precise number of weeks in the academic school year available for teaching, and outreach personnel resources are often limited, developing expansion paradigms is critical. We set out to establish a MT program to increase the number of students served by BioEYES. An effective MT program is of interest to outreach providers that are struggling to increase their reach, sustain teacher partnerships, and recruit new teachers, with minimal impact on staff and costs.

Collaborations between STEM outreach staff and teachers provide learning experiences that are tailored to local school needs. In addition, the active members of these partnerships are diverse and include teachers, administrators, scientists, university students, and informal science educators. Together these stakeholders can accurately frame a scientific phenomenon from multiple perspectives as well as partner on curricula development and provide pedagogical expertise. Having these critical dimensions can build the capacity for a better understanding of the science and the process of science for all involved (Bevan et al., 2010). Yet, successfully creating such a community relies on the formation of a collective vision (Mattessich et al., 2001) that is established through social interactions and grows as individuals develop their own knowledge base (Cochran-Smith, 1991; Robertson, 2007).

Teachers often develop this shared vision and knowledge in a professional development (PD) workshop. However, the effectiveness of teacher-community partnerships involving universities or other outreach partners on teaching and learning is understudied (Blank and de las Alas, 2009; Crockett, 2002; Erickso, et al., 2005; Little, 2002; McGee and Nutakki, 2017), as is research on the combined impact of formal/informal PD opportunities for teachers (e.g., workshops) with on-the-job learning opportunities facilitated by community experts (Parise and Spillane, 2010).

Encouragingly, research on impactful PD for science teachers is beginning to coalesce. Desimone and Garet (2015) characterize a "Conceptual Framework" of features inherent in high-quality PD. The PD features (in bold) include: PD has a specific content focus; teachers take part in active learning; there is a coherence to curriculum, teacher knowledge and beliefs, student needs, and school, district, and state policies; PD is of a sustained duration (20 hours or more per year); and groups of teachers are engaged in collective participation to build learning communities (Desimone and Garet, 2015). This research builds on the foundation laid by a number of researchers (Demonte, 2013; Desimone, 2009; Desimone et al., 2002; Garet et al., 2001; Supovitz and Turner, 2000; Wilson, 2013).

Wilson (2013) shares additional characteristics for high-quality PD that researchers discovered:

> *"Activities are close to practice (Penuel et al., 2007), participants' physical and psychological comfort is taken into account (Freeman et al., 2004), teachers are immersed in inquiry experiences and witness models of inquiry teaching (Supovitz and Turner, 2000), curriculum materials are educative for teachers and students (Davis and Krajcik, 2005; Schneider*

and Krajcik, 2002), and teachers receive direct instruction in the teaching specified in innovative materials (Penuel et al., 2011). Repeatedly, the importance of strong principal support is emphasized (Banilower et al., 2007).”

However, McGee and Nutakki (2017) note that there are constraints to the Conceptual Framework for PD that are unique for urban settings. For example, it is challenging to provide PDs of sustained duration over multiple years, coherence, or collective participation in urban school districts where teacher and principal turnover are common. It is also important to note that the threshold for what constitutes sufficient or sustained duration for a teacher PD has not been established with certainty (McGee and Nutakki, 2017; Yoon et al., 2007). What may be more important is not the number of contact hours, but the quality of the teacher PD paired with inquiry-based instruction that drives student learning (Desimone and Garet, 2015).

It has also been noted that the degree to which individual teachers change as a result of a PD can vary significantly (Fennema et al., 1996; Franke et al., 2001; Franke and Kazemi, 2001; Knapp and Peterson, 1995). Borko (2004) argues that for those who deliver teacher PD the context is an important consideration. For example, while many PD workshops may occur outside of school time, the classroom itself has been shown to provide a powerful context for teacher learning (Ball and Cohen, 1999; Putnam and Borko, 2000). BioEYES has developed a PD program that is performed in both a university and classroom environment providing multiple exposures and contexts for teachers to learn and become comfortable with the program.

Research suggests that if teachers are not comfortable or confident in teaching a subject, they are likely to either not teach it at all, or address it casually, resulting in less effective teachers and underachieving students (Bursal and Paznokas, 2006; Duschl et al., 2007; Nadelson and Idaho National Laboratory, 2012). If you consider these findings in light of the complex content surrounding STEM concepts, the need for content-specific PD is imperative if we are to see gains in student achievement.

In science, hands-on learning is often the norm and is an effective strategy used to teach science since the early 1800s (Lunetta et al., 2007). Hands-on learning involves teamwork with peers, manipulation of objects, a questioning discourse surrounding observations, and the collection of data as a way to understand the natural world. Hands-on activities have been reported to increase learning and achievement in science (Bredderman, 1983; Brooks, 1988; Mattheis and Nakayama, 1988; Saunders and Shepardson, 1984) and to improve science skills (Mattheis and Nakayama, 1988), and attitudes about science, creativity, and language development (Haury and Rillero, 1994). Consistent with these findings, the BioEYES PD process provides similar hands-on opportunities for teachers to become scientists (just like what is asked of their students) by engaging with scientists, and working directly with the scientific equipment and animal models (e.g., zebrafish, microscopes, and scientific supplies). This experience then transitions into a co-teaching experience in their classrooms, allowing for the actualization of the scientific content in the classroom context, and prepares them to become BioEYES MTs.

This paper examines the BioEYES PD design, the characteristics and variables that shape effective MTs in science, the fidelity of programmatic implementation by MTs, and the efficacy of the PD model. The findings presented are applicable to STEM outreach suppliers, educational stakeholders, and teacher PD providers from all disciplines.

PROGRAM ANALYSIS

Here we report an analysis of MTs who utilized the BioEYES program from urban, suburban, and rural areas. We examined the relationship between participating teachers and the BioEYES professional development model. The goals were to evaluate this PD model on three dimensions: 1) through MTs self-reporting on their experience with BioEYES, classroom implementation, and professional development; 2) through a statistical analysis of student learning and attitudes of MT students compared to those students who were co-taught by BioEYES staff members, referred to as outreach educators (OEs); and 3) through a financial analysis of the model.

We sought to answer the following questions:

1. What elements of teacher PD were critical for developing successful MTs?
2. What are MTs’ perceptions of personal characteristics and teaching skills that allow for effective MT implementation?
3. Was there a difference in learning and attitudes for elementary, middle, and high school students in classrooms taught by MTs vs. OEs?
4. To what degree does the financial structure of the MT program pay off for a STEM outreach program?

Participants. *Teachers* – BioEYES MTs are defined as teachers who: participate in BioEYES for three or more years, complete the PD and co-teaching experience for the first two years, and conduct the BioEYES experiment on their own thereafter with equipment loaned from a BioEYES Center. Teachers join the BioEYES program via school district announcements, teacher recommendations, and active teacher recruitment by BioEYES staff. The program does not spend money on marketing and teacher recruitment and has a waitlist in Philadelphia and Baltimore.

In an effort to evaluate the BioEYES MT model, we involved MTs in two ways. First, we invited 50 MTs to complete an online survey in 2013. Thirty-five of the 50 model teachers answered the survey, with 31 of them answering all questions asked. Of the survey respondents, 54% were middle school teachers, 29% elementary teachers, and 17% reported teaching BioEYES at the high school level. Seventy-five percent of the teachers had a master's degree or higher level of education. Roughly half of our model teachers (55%) belonged to a science education professional society and 52% report having had a leadership role at their school. Eighty-five percent of the MTs who completed the survey reported delivering BioEYES to two or more classes, with 24% reaching five or six classes. This finding suggests that MTs are bringing BioEYES to a large number of students each year (more than a single OE can do alone). For example, the year in which the survey was given, 50% of the total students reached in middle and high school (3,196) were taught BioEYES by MTs.

Second, we included a comparison of student learning gains and attitude shifts of MT classrooms in comparison to those classes co-taught by BioEYES OEs. In a 2010-2017 analyses of classrooms taught by BioEYES MTs or BioEYES OEs, 421 teachers were included, with 91 of them becoming MTs by 2017. Broken down by grade level, BioEYES partnered with 212 upper elementary teachers, including 37 MTs; 130 intermediate-level teachers, including 38 MTs; and 104 advanced-level teachers, including 27 MTs. The discrepancy in total teachers (n=421) and teacher count across grade levels (n=446) is due to the fact that some teachers delivered BioEYES to more than one grade level over the seven years or selected different program units within the same grade to accommodate variable student needs.

Students – The student data collected from pre- and post-tests for the 2010-2017 analyses included 8,397 upper elementary students in the 4th/5th grade, 10,641 students in the 7th grade and 7,487 students in the 9th/10th grade. These were students who participated in BioEYES during in-school time, primarily in Baltimore, MD; Philadelphia, PA; South Bend, IN; and Salt Lake City, UT. A small subset of students (75) were also included from pilot areas including Houston, TX (Rice University) and a summer program (KITES, Inc.) in Atlanta, GA.

METHODS

This analysis used a mixed-methods design which included a survey and a statistical analysis of students' pre- and post-assessments. The initial teacher survey provided self-reported data of MTs on the program's PD and co-teaching as well as the program's impact on content familiarity and teaching practices. An analysis comparing student learning and attitudes towards science of MT versus OE classrooms was conducted for the same time span.

Program History. BioEYES offers a weeklong life science outreach curriculum, free to public schools. It was developed to align with the local and national curricular requirements in science for select grade bands: 2nd/3rd, 4th/5th, 7th/8th, and 10th grades and a detailed alignment can be found at http://www.bioeyes.org/teachers/standards/standards-home.php .

Since 2002, BioEYES has reached over 135,000 students nationally through ongoing partnerships with more than 1,300 teachers, including 91 MTs, and is an official partner of the Baltimore City Public School System and the School District of Philadelphia via our major BioEYES programs at the Carnegie Institution and the University of Pennsylvania. Our primary focus is on underserved youth. Both of these school districts have 100% of their students receiving free or reduced-price meals, a low-income indicator, and are comprised of over 79% and 53% African-American students, respectively (Baltimore City Public Schools, 2017; School District of Philadelphia, 2017b). BioEYES is brought to schools and can be done during out-of-school time, yet it primarily occurs during in-school time in a regular classroom setting with the classroom teacher present and participatory.

The experimental design of BioEYES is the same for all grade levels. During the weeklong experiment, each student and their teacher are invited to assume the role of a "scientist" in an important experiment. Students work in groups of four to conduct classroom-based activities. These include a) setting up mating pairs of zebrafish, b) forming hypotheses, c) collecting, observing and counting embryos, d) microscopy e) caring for the fish, f) completing mortality graphs, g) forming conclusions, and h) recording content in scientific notebooks supplied by the program.

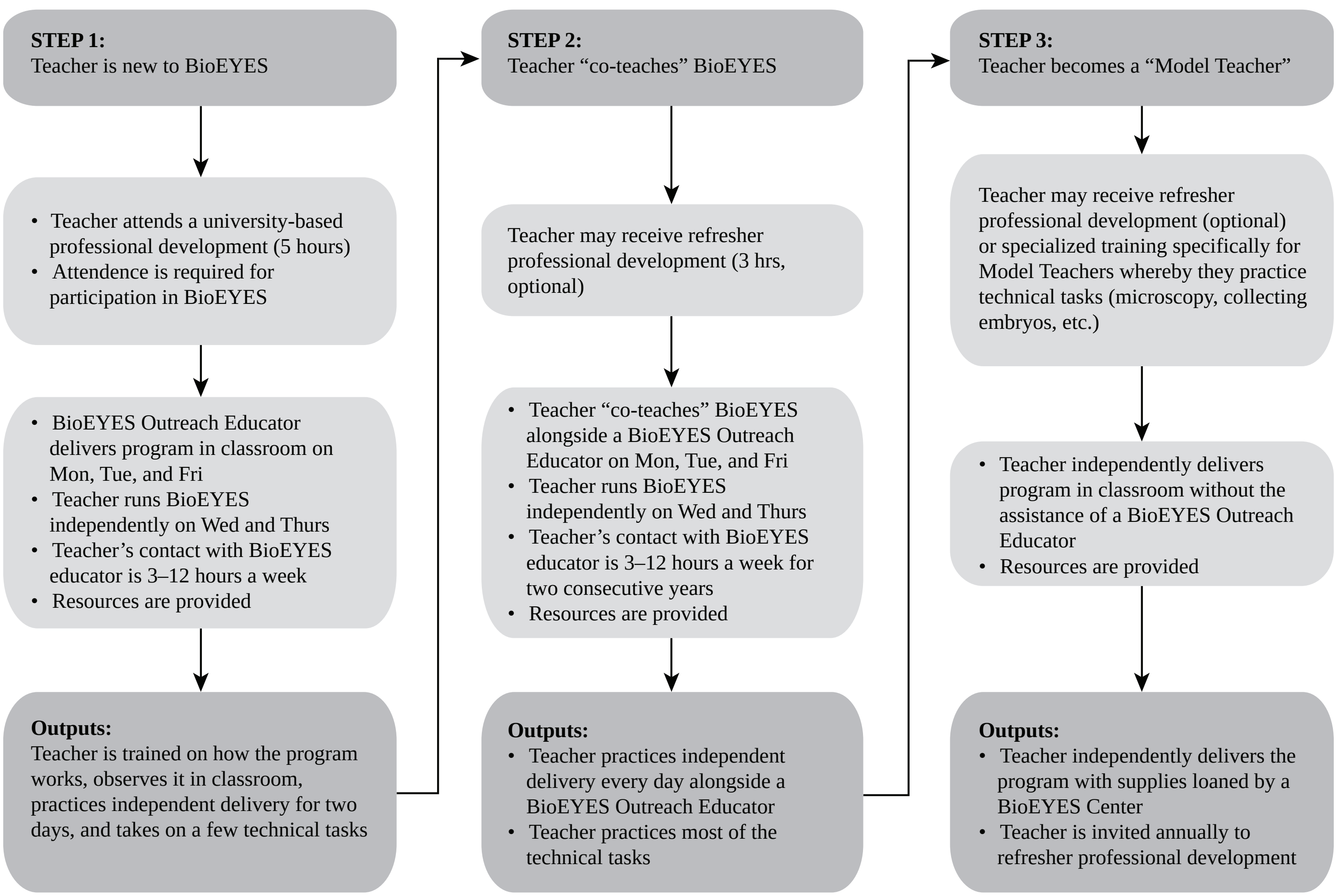
Students engaging as authentic scientists is the mission of BioEYES and we strive to implement best practices across all sites to ensure this. The first practice is to create a "science is about teamwork" experience in each class. Over the week, students work within groups to observe zebrafish behavior and embryo and larvae development under microscopes, and utilize the scientific method. The second practice is to provide guided learning experiences while honoring students' individual and collective ideas. As students learn about genetics and other basic life science topics, students are given room to explore and test their ideas. For example, each day, just like research scientists in the laboratory, students hypothesize, record findings, and think critically about the impact scientific research has on their communities. At each grade level, teachers and outreach staff guide students, but are responsive to questions, new ideas, and to students' data-driven conclusions. The last practice is for each class to understand how science and research impact our community and to discuss STEM careers with them. Providing high-quality microscopes, zebrafish, data journals, and classroom supplies creates the opportunity for students to use equipment found in a lab, learn about model organisms and how they contribute to research, and interact with trained staff that can answer career-related questions.

Being vertebrates, zebrafish are physiologically and genetically comparable to humans, and because they get similar diseases (e.g., cancer and heart disease), they are used to understand human biology (Santoriello and Zon, 2012). Their embryos and larvae are transparent allowing students to observe their growth from a single-cell embryo to a free swimming larva with a beating heart and blood flow in a matter of four days, and for children to make connections about their own biology. Participating teachers regularly report that BioEYES' hands-on approach, with its use of live organisms, fosters student engagement and comprehension of tough science topics (Shuda and Kearns-Sixsmith, 2009).

PD Components. BioEYES utilizes a three-step professional development model (Fig. 1) to train new teachers on the program and to maintain partnerships with existing teachers. These steps are described more fully below and include a 5-hour PD at a university, a 3-day co-teaching experience in a teacher's classroom for two years, and a 3-hour refresher PD at the beginning of each school year. All teachers new to BioEYES must attend the one-day PD, and in years one and two, be present for the classroom co-teaching. Refresher courses are optional, but highly attended. All BioEYES sites provide food at the PDs, but they differ on whether they provide a teacher stipend.

Step 1: One-day professional development. At the initial PD, teachers review the week-long lesson plan and practice the hands-on aspects of the experiment. For example, they assemble and fill the mating tank with water, catch adult fish in a net, draw and describe their observations of both the adult fish and their offspring over the course of their development in scientific journals. This requires that they collect and count the embryos and/or larvae, practice pipetting in order to care for the embryos, and practice microscopy. Since no teacher is a zebrafish expert, all participants start with the same knowledge base (this is true for the students as well). Each teacher receives a teacher manual that includes the daily lesson plans, pictures and descriptions of the science tools used during the week, supplemental STEM resources, and science articles (see Supplement 5 from Shuda et al., 2016). In addition, local scientists volunteer to give a 15- to 20-minute talk or demonstration in a lab setting about their research. This is followed by a tour of the institution's facilities.

Figure 1. BioEYES' three-step teacher professional development model.



Step 2: Three days of co-teaching for two consecutive years. The investment by BioEYES to provide in-class support in the form of OEs until partnering teachers "graduate" to MTs, is an important component of the BioEYES PD model. The role of the classroom teacher during the first two years is to manage the classroom, learn the BioEYES lesson plan and the basics of fish care, and build fundamental scientific skills such as pipetting and microscopy. Their responsibilities grow from year to year, and because teachers spend two days on their own leading the program (Wed/Thurs), they are given the time to practice and make mistakes, yet learn from and reflect with the BioEYES Outreach Educator along the way.

The OE delivers the content in year one and assigns the classroom teacher a few tasks (e.g., helping students look at their fish under a microscope), and co-teaches alongside the classroom teacher in year two. The OE is in the classroom on a Monday, Tuesday, and Friday since these are the days that require greater mastery of the experimental set-up and conclusion. On Wednesday and Thursday, the classroom teacher is on their own, guiding students in caring for the fish, making observations, counting the fish, and graphing their numbers—activities they learned from the teacher PD and through the mentorship of the OE. By year three the MT assumes responsibility for delivering the program without the aid of the OE. The OEs are professionals with teaching and/or science degrees—two of which are former BioEYES classroom teachers—who coordinate with MT the delivery of BioEYES materials and provide guidance to the teacher on how to deliver the lesson plan, conduct the required scientific practices, and how to set up the classroom layout and resources.

When surveyed, 90% of the MTs felt that the one-day PD and the three days of co-teaching (typically for two consecutive years) in the classroom alongside a BioEYES OE was sufficient training on the curriculum.

Step 3: Annual follow-up professional development for Model Teachers. At the beginning of each school year, MTs are invited by BioEYES staff to attend a 3-hour refresher PD. In Philadelphia, this occurs during the second half of the new teacher PD, where MTs have the opportunity to hear about new on going zebrafish research typically performed at the host institution, describe their BioEYES classroom experience to new teachers, network with university staff, faculty, and other teachers, and to schedule their BioEYES week. MTs who attend are often asked to speak about their experience having the BioEYES program in their classroom and are recognized as a valuable partner in the program in front of their peers. Creating opportunities for teachers to network with each other, share their own experiences, and then learn what has worked and what has not has been a valuable experience for teachers.

Assessing Model Teachers' Implementation and Impact. We developed a two-part online survey to evaluate our MTs' perceptions. The first section asked teachers to select, from a predetermined list of teacher attributes, the qualities that a BioEYES MT must possess in order to be effective in delivering the curriculum autonomously. The second part of the survey asked teachers to identify, from a predetermined list of teaching practices, the ones they have learned and adopted after participating in BioEYES, and continued to use throughout the school year. The survey was distributed in the 2012-2013 school year to 50 model teachers and the program received 36 responses.

Assessing Students' Content Knowledge. When BioEYES first started, we were not able to find any validated instruments for K-12 students that were appropriate for our needs. Accordingly, we developed our own set of questions that would serve as our measurement instrument. The authors did not have a student control group because we wanted to provide this opportunity to as many students as possible. We also did not have the staff capacity in the early years of BioEYES to collect data on non-participants. While we evaluate student gains in content knowledge and attitudinal changes every year, from 2002 (when we launched BioEYES) to fall 2014, confidentiality laws and policies precluded the school systems where we operate to allow us to track student alumni that had gone through the BioEYES program. Then, in 2014 the Baltimore City Public School District approved a long-term study of BioEYES students in Baltimore that allows us to track BioEYES "alumni" through high school graduation. A comparison/control group is built into this longitudinal study that is currently ongoing.

Annual reviews of the assessments have occasionally resulted in select questions being changed because it was found that students did not understand the question being asked or the design of the question was confusing. For example, in years past, questions were asked about temperate environments, yet BioEYES largely focuses on tropical environments since that is the habitat for zebrafish. This caused confusion for the students being assessed and we revised our lessons and assessments to better explain the similarity and difference between the two environments. Also, some questions were replaced because students had high scores on the pre test, indicating they already knew the answer (e.g., "what is a hypothesis?"). In short, after completing a study of BioEYES effectiveness and publishing our results (Shuda et al., 2016), we sought to modify/redesign both curriculum and their associated assessments in light of what we learned and to better mesh with shifting local and national curriculum goals.

MTs or OEs administered a pre-test to students prior to the classroom experiment. The post-assessment was given at the end of the experiment. In order to anonymously assess each student's content knowledge towards science before and after the classroom experiments, the students are given an identification number (ID) to replace their name on all instruments. In Philadelphia, this was different than the student ID delegated by the school. In Baltimore however, anonymous IDs were used until fall 2014. Thereafter school district IDs were used. All pre- and post-student data is entered into a database using the ID numbers to pair each pre- and post-test. Students were asked to answer a set of knowledge-based questions, where the answers were either multiple choice with one correct answer out of four, or true/false. Correct answers for each question were assigned a value of 1, and incorrect or skipped answers were given a value of 0. Overall correct percentages were calculated for each question on both the pre- and the post-assessments, along with the difference between the two and the direction of change. A two-tailed paired t-test was then performed on each question's results, a Bonferroni correction was applied to each question's p-value to adjust for multiplicity, and a p-value of 0.05 was set as the level of significance. Analysis was done at the 4th/5th grade, 7th grade, and 9th/10th grade levels.

Assessing Students' Attitudes Towards Science and Scientists. On the same pre- and post-test described above, students were asked to rate a set of attitude-based statements on a five-point Likert scale, where "Strongly disagree" = 1, "Disagree" = 2, "Neither" = 3, "Agree" = 4, and "Strongly Agree" = 5. The difference between each student's pre- and post-response was calculated, along with the average overall difference for each statement and the overall direction of change. Responses that were missing either a pre- or a post-response were not included in the analysis. A two-tailed paired t-test was performed on each statement's results, followed by a Bonferroni correction to each statement's p-value to adjust for multiplicity. A p-value of 0.05 was set as the level of significance.

Financial Commitment. Finally, a cost benefit analysis was conducted within the Philadelphia and Baltimore sites to discover the true cost of the multi-step professional development model. These sites were selected because of the similar demographic served and target teacher enrollment in the program per year. They are also situated within research institutions that provide indirect in-kind support and zebrafish facilities. The annual investments were broken out into several categories including the personnel cost of the outreach educator, equipment, consumables, travel, evaluation, and professional development. Administrative costs and office space were not included as they are supported by the universities. The cost analysis was conducted by grade level, teacher, and student and based on a class of 30 students.

RESULTS

Question 1: What elements of teacher professional development were critical for developing successful MTs?

The BioEYES team developed PD goals that were consistent across all sites and MTs provided feedback on how these goals prepared them for classroom implementation of BioEYES. The goals were rated using a Likert scale of 4 (very useful) to 1 (not useful). The following shows the percent of respondents (n=36) who rated each goal as 4 (very useful), furnishing evidence that they are implemented consistently across sites: Goal 1, Ensuring that all participants had a comprehensive introduction to zebrafish (81%); Goal 2, Preparing teachers to effectively teach the BioEYES content (84%); Goal 3, Preparing for classroom implementation (74%); Goal 4, Knowledge of the alignment to grade-specific and district-specific curriculum (68%); Goal 5, Professionalism and knowledge of the outreach staff and their roles (87%); and Goal 6, Providing opportunities to engage with other teachers (68%).

When model teachers were asked on the survey how BioEYES professional development differs from other science trainings that teachers have attended, the following sample responses were shared:

- "They offered scientific information in addition to how to teach the units."
- "It was interactive and very thorough. Teachers left feeling empowered and confident about teaching the curriculum!"
- "Training was immediately relevant to classroom implementation, involved multiple presenters, and a great deal of hands-on experience."
- "It was excellent connecting the lab experience, to bio content, to standards. This is different than most PD that usually focuses on one."

Overall, teachers thought that providing hands-on science with the assistance of a BioEYES OE was most beneficial. We found that classroom management was identified as least beneficial. This question served as a control in that classroom management training was not provided and it is not a focus of BioEYES. This finding was consistent between survey instruments. It is discussed in the analysis of Question 2, below.

Although it is not mandatory, 94% of the model teachers we surveyed reported attending the refresher PDs annually, illustrating the value of ongoing PD support, especially for complex subjects such as those found in STEM.

Question 2: What are MTs' perceptions of personal characteristics and teaching skills that allow for effective MT implementation?

MT Attributes. Teachers were asked to rate the following attributes independently from 4 (most important) to 1 (least important): competence, confidence, enthusiasm, and classroom management in a science classroom. The results indicated that all four attributes are needed, but at varying importance. (Table 1) Competence and enthusiasm for teaching science were the top two attributes identified by MTs (84% rated it a 4). This was followed by confidence (71% rated it a 4).

Interestingly, confidence was repeatedly shared when asked, "In your own words, what makes you an effective MT for this program? What challenges do you face as a MT?" Teachers responded:

- "An effective model teacher needs to be extremely confident and well prepared. He or she must possess excellent management in order to ensure the safety of the equipment and the fish. Students must be able to work in groups. The teacher must be able to have different groups of students doing different things."
- "Enthusiasm, confidence, good classroom management are essential for this program. Time constraints in our school schedule are the biggest challenge."
- "An effective model teacher collaborates with students while facilitating learning. A strong knowledge evidence-based background encourages students to have confidence in concepts being presented. A model teacher must be open to frequent stops to process knowledge in written and oral form. A model teacher needs to give up the idea of "control." Time is the biggest challenge faced as a model teacher."

Classroom management garnered the most diverse responses of all for MTs. In fact, competence, enthusiasm, and confidence all received a rating of 3 (important) and 4 (very important) on the scale. For classroom management, 55% felt it was very important; 39% felt it was important; and 6% felt it had limited importance.

The survey also asked MTs to self-report the impact the BioEYES program had made on their daily teaching practices. An overwhelming majority of MTs (93%) stated that the teaching practices learned from BioEYES have helped them integrate inquiry-based teaching long-term in their classrooms. More than half (53%) of the MTS reported that BioEYES helped improve collaborative inquiry and collaborative discourse and 43% felt that BioEYES impacted their ongoing efforts to mimic science practices through hands-on activities and science experiments throughout the school year.

Teachers were asked to share examples of how they have implemented the teaching practices they have identified.

> *"My science lessons integrate many of the teaching practices in BioEYES… for a unit called 'Variables,' students work in pairs to create a system such as a pendulum. Beforehand, I model the making of the pendulum and what the goal at hand is.... Student pairs then 'mimic scientific practices' and have 'access to equipment' by making a pendulum with their partner and then they engage in collaborative discourse to figure out what might affect the number of swings." —BioEYES Model Teacher, grade 4*

> *"BioEYES makes it very easy to integrate collaborative inquiry. After we complete the BioEYES lessons, we start to discuss evolution. I use an online game where groups of students must decide if species survive based on their phenotype." —BioEYES Model Teacher, grade 4*

Question 3: Was there a difference in learning and attitudes for elementary, middle, and high school students in classrooms taught by MTs vs. OEs?

An analysis comparing students from MT and OE classrooms found a similar effectiveness on student learning across all three grade bands, and positive attitude changes about science as a result of the program, regardless of who implemented the lesson. A breakdown of the grade levels is shown below and in Table 2-3 and Sup. Tables 1a-6.

Elementary School Knowledge and Attitudes (4th/5th grade). On six of the knowledge questions (K1, K2.1, K3, K4, K5.2, and K6.1) the MTs' students came in with a significantly higher knowledge base than with the OEs' students. The remaining questions showed no significant difference

Table 1. *BioEYES Model Teacher Research Survey, Winter 2013*

Rate how important the following characteristics are for a model teacher to possess: (1: not important – 4: most important)

	1 (not important)		2		3		4 (most important)		Total
Confidence in teaching the curriculum	0%	0	0%	0	29%	9	71%	22	31
Competence in teaching the curriculum	0%	0	0%	0	16%	5	84%	26	31
Enthusiasm for teaching hands-on science	0%	0	0%	0	16%	5	84%	26	31
Classroom management skills	0%	0	6%	2	39%	12	55%	17	31
								Answered	**31**
								Skipped	**4**

Table 2. *Total Knowledge Results, 2010-2017*

		OE average	MT average	OE/MT difference	Adjusted p-value
Elementary School (*n*=8397)	Total PRE average	45.70%	50.70%	5.00%	<0.001
	Total POST average	70.90%	74.30%	3.40%	<0.001
	Total average difference	25.20%	23.60%	-1.60%	0.002
Middle School (*n*=10641)	Total PRE average	57.20%	58.90%	1.70%	<0.001
	Total POST average	72.80%	75.20%	2.40%	<0.001
	Total average difference	15.70%	16.40%	0.70%	0.067
High School (*n*=7487)	Total PRE average	50.60%	58.00%	7.40%	<0.001
	Total POST average	65.30%	73.20%	8.00%	<0.001
	Total average difference	14.70%	15.30%	0.50%	0.265

Shading indicated significance

Table 3. *Total Attitude Results, 2011-2017*

		OE average	MT average	OE/MT difference	Adjusted p-value
Elementary School (total *n*=6682)	Total PRE average	3.67	3.68	0.01	0.259
	Total POST average	3.76	3.75	0	0.642
	Total average diff.	0.09	0.07	-0.02	0.098
Middle School (total *n*=9421)	Total PRE average	3.55	3.54	-0.01	0.311
	Total POST average	3.58	3.57	-0.01	0.128
	Total average diff.	0.03	0.03	0	0.463
High School (total *n*=6433)	Total PRE average	3.58	3.68	0.1	<0.001
	Total POST average	3.63	3.71	0.08	<0.001
	Total average diff.	0.04	0.03	-0.02	0.019

Shading indicated significance

Table 4. *Cost benefit analysis comparing teacher types: dependent (teacher + outreach educator) vs. independent (teacher only).*

YEAR 1 & 2: DEPENDENT TEACHER	YEAR 3+: INDEPENDENT TEACHER
Activities & Inputs	**Activities & Inputs**
· University-based professional development (3–5 hrs)	· University-based refresher professional development (1.5–3 hrs)
· Three days of co-teaching (teacher + outreach educator) in classroom	· Teacher is independently running program as a BioEYES Model Teacher in classroom
· Resources are provided	· Resources are provided
Cost to BioEYES (per year, per teacher)	**Cost to BioEYES (per year, per teacher)**
· ES: $540.25 MS: $883.40 HS: $1,054.99	· ES: $262.16 MS: $426.10 HS: $508.03
· Cost increase in upper grades is due to greater # of classes and increase in staff time involved with direct instruction in classroom	· Cost decreases by year 3+ because staff time in the classroom is omitted · On average, cost/teacher and cost/student is reduced by 48.3%
$30/student **$826/teacher**	**$14/student** **$399/teacher**

on the pre-test questions. Six of the questions (K2.0, K2.1, K3, K6.1, K8.0, and K8.1) showed the OE having a greater amount of improvement over the MT, while on K7 the MT had significantly more improvement.

In the aggregate, the MT had significantly higher scores on both the pre- and post-test (5% and 3% greater, respectively), while the OE showed significantly but very slightly greater improvement (2%). In short, the MTs' students started and ended with higher scores, but didn't improve by the same degree, possibly because there was less room for improvement.

For attitudes, there were significant differences in the pre-test values of seven statements (A2, A3.1, A6, A7, A8, A10, and A11). Four were in the MTs' favor, and three were in the OEs' favor. None of the questions showed a difference in the amount of improvement. The aggregate scores showed no significant differences.

Middle School Knowledge and Attitudes (7th grade). Few differences were found between the MTs' and OEs' classrooms. Five knowledge questions (K1.1, K2.1, K3, K5, and K8) showed a significant difference on the pre-test, generally in the MTs' favor. There was only a significant difference in improvement on four questions: K4.0, K4.1, K5, and K8, where three were in the OEs' favor and three favored the MTs.

In the aggregate, there were significant though slight differences between the pre- and the post-test averages (2% each, respectively), both in the MTs' favor. There was no significant difference in the overall improvement between the OE and the MT (1%). In other words, the students taught by MTs started slightly higher, and ended correspondingly higher. For attitudes, no significant changes were found when comparing the MTs' and OEs' pre- and post-tests.

High School Knowledge and Attitudes (9/10th grade). There was a significant difference between the pre-test averages, with all but one knowledge question (K5.1, a fairly esoteric question about somites that the students were unlikely to be familiar with prior to BioEYES) in favor of the MTs. Only three questions, though, show a significant difference in the amount of improvement (K3.1, K6, and K7), with one in the MTs' favor and two that favored the OEs.

The aggregate pre-test showed the MTs had a significantly higher pre-test score than the OEs, by 7%. The MTs scored correspondingly higher on the post-test, by 8%. There was no significant difference in improvement between the MT and the OE (0.5%). That is to say, the MTs' students started with a greater knowledge base than the OEs' students, but both groups improved by about the same amount.

For attitudes, there were significant differences on the pre-value for eight statements (A1, A2, A3.1, A5, A6, A7, A10, and A11), all in favor of the MTs. However, there were no significant differences found in the amount of improvement between the pre- and post-test of MTs or OEs.

Question 4: To what degree does the financial structure of the Model Teacher program pay off for a STEM outreach program?

The two-year financial investment in training and co-teaching with teachers decreases by ~50% after the teachers "graduate" to MT status (Table 4). In the first two years of the BioEYES model, the average program cost for each teacher is $826 per year. The cost per teacher increases by the grade level in which they teach: $540 (elementary), $883 (middle), and $1,055 (high). The cost increase is due to a greater number of classes and increase in staff time involved with direct instruction in classroom. The cost per student averaged $30 per week ($6 per class day) when estimating a class size of 30 students.

It was found that when a co-teacher became a MT in year three, the per teacher investment was reduced by 48.3% at an average teacher cost of $399. Again, the cost increased by grade level due to the amount of supplies purchased for multiple classes: $262 (elementary), $426 (middle), and $508 (high). The cost per student fell to $14 per student in a class of 30 students.

BioEYES educators are hired for either full time or seasonal (full time at 9 months/year) positions. The seasonal positions decrease the program's expenses. Those BioEYES educators who are 12-month employees use the summer to process and analyze student data, update curriculum and teaching tools, as well as lead summer programs. These factors were included in the cost/benefit analysis. The BioEYES PD model assists in keeping a modest program budget, realistic program goals, and securing long-term partnerships with teachers.

DISCUSSION

Project BioEYES was developed for an urban, K-12 public school district over 15 years ago, and has since been replicated in multiple locations and with positively significant outcomes on teaching and learning for teachers and students. Its university-teacher model of teacher PD was conceived well before a framework for effective teacher PD was identified by researchers. However, there are some key features described in the literature (Demonte, 2013; Desimone, 2009; Desimone and Garet, 2015; Desimone et al., 2002; Garet et al., 2001; McGee and Nutakki, 2017; Supovitz and Turner, 2000; Wilson, 2013; Yoon et al., 2007) as being important for teaching and learning that are embedded in BioEYES' teacher PD model. The BioEYES teacher PD model is focused on life science (content focus) and teachers engage in hands-on learning and co-teaching in the classroom (active learning). The units are also iteratively aligned with current learning standards such as the Next Generation Science Standards and state and district standards and curriculum goals (coherence). Teachers are provided between 9–15 contact hours per year (sustained duration) of BioEYES PD (Fig. 1), which is slightly less than some researchers advocate. However, the urban districts where we operate have a high rate of turnover for teachers and principals and thus this potentially makes it more difficult to engage teachers not only for one year, but on a continual basis. Yet our findings show that the BioEYES teacher PD model has been successful at retaining teachers over multiple years as well as engaging them in co-teaching and refresher trainings, positively influencing their knowledge and competence when asked to self-reflect on the BioEYES experience, improving learning, and noting gains in attitudes among students in science.

While teachers do engage in collective participation during BioEYES teacher PDs—where teams of teachers from the same school, grade or school district participate; or teachers have an opportunity to seek advice and collaborate to adapt lessons in the classroom—this area has not been studied by our team and could benefit from further exploration.

Over the past 15 years of Project BioEYES, there had not been a systematic analysis to gauge its effectiveness. As an initial step, we first determined if students learned the BioEYES curriculum (content knowledge) and whether it altered their STEM-related attitudes immediately after completing the activity (Shuda et al., 2016). We then undertook the analysis described herein to understand the effectiveness of the MTs at delivering BioEYES content in the absence of BioEYES educators.

I. Comparison of Outcomes for Model Teachers vs. Outreach Educators. We examined the growth of student learning and improved attitudes in classrooms taught by MTs versus OEs and asked MTs to identify the essential characteristics that they believe lead to an effective MT.

Content Knowledge – MTs tended to both start and end with higher student scores at the grade levels we studied. However, there was no significant difference in the amount of improvement for middle school or high school student scores, and only a minimally significant difference for upper elementary student scores in the OEs' favor (Question 4). A possible explanation for these results could be that school teachers who are strong, effective teachers and engage more fully with their students are more likely to become MTs, and are also more likely to start their students with a higher knowledge base. Therefore, MTs can make more connections to the curriculum and what students already know over a longer period of time than OEs can. This observation supports our contention that giving high quality STEM programing that includes state-of-the-art PD to well-trained teachers generates the strongest possible outcome.

The aggregate pre-test score was significantly higher for the MTs. The OEs showed a slight but significantly greater amount of improvement (a difference of 0.02). The MTs' students started with better attitudes towards science and did improve, though less than the OEs, possibly because there wasn't as much room for improvement.

Regardless of who taught BioEYES, significant content knowledge gains were seen, indicating that MTs and OEs are similarly effective, and that MTs are implementing BioEYES with fidelity. Seeing students' content knowledge increase strengthens the PD model's impact on training teachers to autonomously deliver the BioEYES curriculum to the same caliber as if an outreach educator was present. This helps BioEYES staff evaluate whether all students receive the same content. It is expected that some students will have pre-existing knowledge based on a previous exposure to genetics. Although we emphasize that prior knowledge of genetics is unnecessary, we understand that some teachers will expand on the content during BioEYES, which can impact assessment results. Also, it is possible that students experienced BioEYES in previous years. While the grade level units do vary, some of the basic techniques and scientific definitions are repeated. We then expect that students will retain some knowledge during each exposure and put it into practice as they experience BioEYES at different grade levels.

Student Attitudes – We saw no difference in student attitudes about science and scientists regardless of teacher type except in one instance: the aggregate pre-test score was significantly higher for students taught by a high school MT. Students taught by an OE showed a slight but significantly greater amount of improvement in attitudes (a difference of 0.02). The MTs' students started with better attitudes towards science and did improve, though not by as much as the OEs' students, possibly because there was less room for improvement. These findings add to the wide body of knowledge that changing students' attitudes is an extremely difficult task. When surveyed, less than half of all MTs felt their students were more engaged with an OE in the classroom, yet our data indicates that well trained professional science educators, whether classroom teachers or outreach educators, can positively shift attitudes in all grade levels. This is an area of research that would benefit from further exploration.

II. Elements of Teacher Professional Development Critical for Developing Effective Model Teachers. *What makes an effective model teacher (model teacher perceptions)* – MTs felt that competence in teaching science and enthusiasm for teaching hands-on science were important qualities (Question 2). Because STEM often contains complex content, and because teachers may feel underprepared in these areas (Fulp, 2002), competence in teaching the content may rate as important to them. And if the content is difficult for a teacher, it is likely to be equally more challenging for the student. Thus, imparting enthusiasm for the subject may be perceived as a way for teachers to engage students in content and skills that take time and practice to master.

Also, consider that a MT designation may be viewed as a leadership position for teachers. If science experts feel a teacher is competent enough to conduct a zebrafish experiment autonomously, does this increase a teacher's confidence (also ranked as important to teachers, but less so than other factors) and perceptions of competence in themselves? Recognizing they are likely more invested and therefore motivated as MTs, this may also increase their enthusiasm. But this could also be a result of novel curriculum or the "cool factor" of zebrafish that causes this reaction.

As the MT survey found, teachers felt that having the assistance of an OE was a benefit of the BioEYES program. This may be because as teachers embark on hands-on experimentation with their students, perhaps for the first time, the complexity of the content and the "messiness" inherent in the activity are heightened, thereby necessitating more teacher support and mentorship. During BioEYES, students are required to follow the scientific method as a class, in small groups, as well as individually. Stations for embryo harvesting, microscopy, and data analysis are set up. Students-as-scientists may be a new instructional model for a teacher, and having an OE demonstrate how to manage the activities is helpful. For a teacher with limited resources or opportunities to provide this type of learning experience on their own, they benefit from having a co-teacher share these responsibilities. As noted in the survey results, having an OE on hand to answer scientific and technical questions that either teachers or their students might have is beneficial.

There is a small subset of BioEYES teachers (3-5%) who never graduate to MT status. This may be because they have shifted between grades and schools and continue to need assistance adjusting the experiment to their students' needs, lack of confidence in implementing BioEYES autonomously, or simply only interested in co-teaching the experiment with a lack of interest in assuming ownership of the program. The feedback we most often get from teachers who resist becoming a MT is that their students love when they have a guest teacher. Yet when we asked MTs if they felt their students were more engaged when an outreach educator was present, less than half (48%) said yes. The program has added incentives for teachers to move to MT status, when ready. These include reviewing and piloting new lessons first, and joining the BioEYES team at community events as a featured teacher. Nonetheless, some teachers are not willing to become a MT, yet the partnership remains.

BioEYES is unusual in that it provides ongoing collaboration with teachers, with full-day workshops and in-class support offered over multiple years. This is unlike many science education programs or science resources where teachers may receive a few hours of instruction and tutorial and are then expected to implement the resource in the classroom on their own. The BioEYES approach is consistent with the literature. For example, exposing teachers to guided, inquiry-based experiences during professional development mirrors the best practices for engaging students in science classrooms (McCarthy and Bellina, 2003; National Research Council, 1996, 2000). BioEYES' collaborative PD allows teachers to ask questions and seek help during the introductory workshop and while they are implementing the program in their classroom, effectively increasing the competence, and confidence of teachers in doing hands-on science (Questions 1 and 2). It is also worth noting that by offering refresher PDs, teachers have a chance to increase their content knowledge even further and through different mechanisms—conversation with outreach staff and other teachers, presentations by scientists, and lab demonstrations—which can lead to improved teaching practices (Cohen et al., 1998). While it may be that these types of refresher PD experiences are critical to BioEYES' success, a future study would have to test this hypothesis.

The BioEYES PD is a balance between reviewing the content specified in the daily lesson plans—life science content that teachers are already mandated to teach—and the use of scientific practices and tools (e.g., animal models and microscopy). Teachers are active learners completing tasks such as catching fish and collecting embryos in small groups, giving them the opportunity to mimic what will occur in their classroom. They are asked to model what their students will do and learn during the BioEYES week to ensure they are comfortable with what will be asked of them and their students. This leads to more collaboration among new teachers to the program and the outreach educator since the teacher knows the steps of the experiment prior to implementation.

III. How the BioEYES Model Benefits Science Providers. This type of PD model, which blends a PD workshop with real-time classroom teaching and ongoing refresher trainings and support, allows outreach providers to build strong relationships with teachers and within the schools, and to experience first-hand the learning environment and the possible challenges that teachers and providers might face. Such insight allows for the OE and teachers to tailor the BioEYES experiment to fit their classroom needs. For example, by using a high school unit for gifted middle school students, or by using technology to allow students with special needs to observe what is under the microscopes when they physically can't do it themselves. Moreover, it is instructive that teachers value having an OE support them in their classroom, and who provides them the time, expertise, and resources to repeatedly practice the skills needed to deliver hands-on science. Often, several teachers from the same school attend a

BioEYES PD together so that teachers from the same grade can be trained. This is an efficient way to provide BioEYES to a larger number of students and teachers at each school, and to reduce program costs since travel and teaching time are minimized. While PDs are held at each institution, they can also be offered off site, though teachers would miss out on meeting scientists, seeing a scientific setting, or visiting animal facilities—all value-added experiences for teachers and ones they report to enjoy.

Assisting MTs on educational grants has helped teachers secure equipment for the BioEYES lesson (e.g., fish tanks and microscopes) that directly leads to cost savings for the program. An added important benefit is that these science resources can be used elsewhere in the science curriculum. For example, students have used zebrafish for science fair projects.

In summary, this paper describes a three-step teacher PD model that is rooted in a training at a science institution and in the classroom and examines its impact on creating autonomous, effective teacher partners. We found that our full-day workshop, co-teaching experience in the classroom, and refresher workshops provide sufficient training for teachers to gain the competence to teach genetic and life science curricula, and instill confidence and enthusiasm for implementing hands-on science. In addition, this PD model has provided a network of MTs that disseminate the BioEYES program, thereby reducing program expenses, allowing for new teachers to receive training and programming, and effectively expanding program capacity. This outreach-teacher partnership garners the most impact when a system is built comprised of high quality STEM programming, multiple PD exposures in different contexts, and well-trained teachers and outreach staff. Even more beneficial is that students who participate in the BioEYES experience with their classroom teacher or co-taught by an OE have improved content knowledge in the areas of scientific process and life science, as well as positive attitude shifts, across the elementary, middle, and high school grade levels.

ASSOCIATED CONTENT

Supplemental documents referenced in this manuscript are uploaded to the same webpage and available for download.

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ABBREVIATIONS

MT: Model Teachers; OE: Outreach Educators; PD: Professional Development;

REFERENCES

Ball, D.L., and Cohen, D.K. (1999). Developing practice, developing practitioners: Toward a practice-based theory of professional education. San Francisco: Jossey-Bass Publishers.

Baltimore City Public Schools. (2017). Baltimore City Schools at a Glance. Retrieved from http://www.baltimorecityschools.org/about/by_the_numbers

Banilower, E.R., Heck, D.J., and Weiss, I.R. (2007). Can professional development make the vision of the standards a reality? The impact of the national science foundation's local systemic change through teacher enhancement initiative. Journal of Research in Science Teaching, 44(3), 375-395.

Bevan, B., Dillon, J., Hein, G.E., Macdonald, M., Michalchik, V., Miller, D., Root, D., Rudder, L., Xanthoudaki, M., and Yoon, S. (2010). Making science matter: Collaborations between Informal science education organizations and schools. Washington, DC: Center for Advancement of Informal Science Education (CAISE).

Blank, R.K., and de las Alas, N. (2009). The effects of teacher professional development on gains in student achievement: How meta analysis provides scientific evidence useful to education leaders. Washington, DC: Council of Chief State School Officers.

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. Educational Researcher, 33(8), 3-15.

Bredderman, T. (1983). Effects of activity-based elementary science on student outcomes: A quantitative synthesis. Review of Educational Research, 53(4), 499-518.

Brooks, R.C. (1988). Improving student science achievement in grades 4-6 through hands-on materials and concept verbalization: Roger C. Brooks, 11 Auburn Street, Concord, NH 03301 ($10.00, complete document with appendices).

Bursal, M., and Paznokas, L. (2006). Mathematics anxiety and preservice elementary teachers' confidence to teach mathematics and science. School Science and Mathematics, 106(4), 173-180.

Cochran-Smith, M. (1991). Reinventing student teaching. Journal of Teacher Education, 42(2), 104-118.

Cohen, D.K., Hill, H.C., and Consortium for Policy Research in Education. (1998). Instructional policy and classroom performance: The mathematics reform in California. Philadelphia, PA: Consortium for Policy Research in Education, University of Pennsylvania, Graduate School of Education.

Crockett, M.D. (2002). Inquiry as professional development: Creating dilemmas through teachers work. Teaching and Teacher Education, 18(5), 609-624.

Davis, E.A., and Krajcik, J.S. (2005). Designing educative curriculum materials to promote teacher learning. Educational Researcher, 34(3), 3-14.

Demonte, J. (2013). High-quality professional development for teachers: Supporting teacher training to improve student learning. Washington, DC: Center for American Progress.

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

Desimone, L.M., and Garet, M.S. (2015). Best practices in teachers' professional development in the United States. Psychology, Society and Education, 7(3), 252-263.

Desimone, L.M., Porter, A.C., Garet, M.S., Yoon, K.S., and Birman, B.F. (2002). Effects of professional development on teachers' instruction: Results from a three-year longitudinal study. Educational Evaluation and Policy Analysis, 24, 81-112.

Duschl, R.A., Schweingruber, H.A., Shouse, A.W., and National Research Council Committee on Science Learning K-8. (2007). Taking science to school: Learning and teaching science in grades K-8.

Erickson, G., Gabriella, M.B., Mitchell, I., and Mitchell, J. (2005). Collaborative teacher learning: Findings from two professional development projects. Teaching and Teacher Education, 21, 787-798.

Fennema, E., Carpenter, T.P., Franke, M.L., Levi, L., Jacobs, V.R., and Empson, S.B. (1996). A longitudinal study of learning to use children's thinking in mathematics instruction. Journal for Research in Mathematics Education, 27(4), 403-434.

Franke, M.L., Carpenter, T.P., Levi, L., and Fennema, E. (2001). Capturing teachers generative change: A follow-up study of professional development in mathematics. American Educational Research Journal, 38(3), 653-689.

Franke, M.L., and Kazemi, E. (2001). Beyond classical pedagogy: Teaching elementary school mathematics. In Wood, T.L., Nelson, B.S. and Warfield, J. (Eds.). Mahwah, N.J.: L. Erlbaum Associates.

Freeman, J.G., Marx, R.W., and Cimellaro, L. (2004). Emerging considerations for professional development institutes for science teachers. Journal of Science Teacher Education, 15(2), 111-131.

Fulp, S.L. (2002). 2000 national survey of science and mathematics education: Status of elementary school science teaching. Chapel Hill, NC: Horizon Research, Inc.

Garet, M.S., Porter, A.C., Desimone, L., Birman, B.F., and Yoon, K.S. (2001). Section on teaching, learning, and human development - What makes professional development effective? Results from a national sample of teachers. American Educational Research Journal, 38(4), 915.

Handelsman, J., and Smith, M. (2016, February 11). STEM for All [Blog post]. Retrieved from https://obamawhitehouse.archives.gov/blog/2016/02/11/stem-all

Haury, D.L., and Rillero, P. (1994). Perspectives of Hands-On Science Teaching: ERIC Clearinghouse for Science, Mathematics and Environmental Education. Retrieved from https://eric.ed.gov/?id=ED372926

Knapp, N. F., and Peterson, P. L. (1995). Teachers' interpretations of "CGI" after four years: Meanings and practices. Journal for Research in Mathematics Education, 26(1), 40.

Little, J.W. (2002). Locating learning in teachers communities of practice: opening up problems of analysis in records of everyday work. Teaching and Teacher Education, 18(8), 917-946.

Lunetta, V.N., Hofstein, A., and Clough, M.P. (2007). Learning and teaching in the school science laboratory: An analysis of research, theory and practice [Google Books Version]. In Abell, S.K. and Lederman, N.G. (Eds.), Handbook of research on science education (pp. 393-441). Retrieved from https://books.google.com

Maryland State Department of Education. (2016). The 2016 Maryland report card. Retrieved from http://reportcard.msde.maryland.gov/

Mattessich, P.W., Murray-Close, M., Monsey, B.R., Wilder Research Center, and Amherst H. Wilder Foundation. (2001). Collaboration: What makes it work - A review of research literature on factors influencing successful collaboration. Saint Paul, Minn.: Fieldstone Alliance.

Mattheis, F.E., and Nakayama, G. (1988). Effects of a laboratory-centered inquiry program on laboratory skills, science process skills, and understanding of science knowledge in middle grades students. Retrieved from https://files.eric.ed.gov/fulltext/ED307148.pdf

McCarthy, D., and Bellina, J.J. (2003). Saint Mary's College Teacher Science Institute: Converting teachers to using guided inquiry for science curricula. Journal of Higher Education Outreach and Engagement, 8(1), 167-178.

McGee, S., and Nutakki, N. (2017). The impact of adapting a general professional development framework to the constraints of in-service professional development on the Next Generation Science Standards in Urban Settings. Journal of Urban Learning, Teaching, and Research, 13, 73-89.

Nadelson, L., and Idaho National Laboratory. (2012). iSTEM summer institute: An integrated approach to teacher professional development in STEM. Journal of STEM Education, 13(2), 69-83.

National Academy of Sciences. (2007). Rising above the gathering storm : Energizing and employing America for a brighter economic future. Washington, DC: National Academies Press.

National Academies of Sciences, Engineering, and Medicine. 2018. Science and Engineering for Grades 6-12: Investigation and Design at the Center. Washington, DC: The National Academies Press. doi: https://doi.org/10.17226/25216

National Research Council. (1996). National science education standards. Washington, DC: The National Academies Press.

National Research Council. (2000). Inquiry and the national science education standards: A guide for teaching and learning. Washington, DC: The National Academies Press.

Parise, L.M., and Spillane, J.P. (2010). Teacher learning and instructional change: How formal and on-the-job learning opportunities predict change in elementary school teachers' practice. The Elementary School Journal, 110(3), 323-346.

Penuel, W.R., Fishman, B.J., Yamaguchi, R., and Gallagher, L.P. (2007). What Makes Professional Development Effective? Strategies That Foster Curriculum Implementation. American Educational Research Journal, 44(4), 921-958.

Penuel, W.R., Gallagher, L.P., and Moorthy, S. (2011). Preparing teachers to design sequences of instruction in earth systems science: A comparison of three professional development programs. American Educational Research Journal, 48(4), 996-1025.

Putnam, R.T., and Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? Educational Researcher, 29, 4-16.

Robertson, A. (2007). Development of shared vision: Lessons from a science education community collaborative. Journal of Research in Science Teaching, 44(5), 681-705.

Santoriello, C., and Zon, L.I. (2012). Hooked! Modeling human disease in zebrafish. The Journal of Clinical Investigation, 122(7), 2337–2343. http://doi.org/10.1172/JCI60434

Saunders, W.L., and Shepardson, D. (1984). A comparison of concrete and formal science instruction upon science achievement and reasoning ability of sixth grade students. Journal of Research in Science Teaching, 24, 39-51.

Schneider, R.M., and Krajcik, J. (2002). Supporting science teacher learning: The role of educative curriculum materials. Journal of Science Teacher Education, 13(3), 221-245.

School District of Philadelphia. (2017a). 2017 PSSA and AYP Results. Retrieved from https://www.philasd.org/performance/pssakeystone/

School District of Philadelphia. (2017b). District view of enrollment. Retrieved from https://dashboards.philasd.org/extensions/philadelphia/index.html#/

Shuda, J., and Kearns-Sixsmith, D. (2009). Outreach: Empowering students and teachers to fish outside the box. Zebrafish, 6(2), 133-138.

Shuda, J.R., Butler, V.G., Vary, R., and Farber, S.A. (2016). Project BioEYES: Accessible Student-Driven Science for K-12 Students and Teachers. PLoS Biol, 14(11), e2000520. https://doi.org/10.1371/journal.pbio.2000520

Supovitz, J.A., and Turner, H.M. (2000). The effects of professional development on science teaching practices and classroom culture. Journal of Research in Science Teaching, 37, 963-980.

U.S. Department of Education. (1984). National Commission on Excellence in Education, A nation at risk: The full account. Cambridge, MA: USA Research.

U.S. Department of Education. (2000). Before it's too late : A report to the nation from the National Commission on Mathematics and Science Teaching for the 21st Century. Washington, DC: U.S. Department of Education.

U.S. Office of Science and Technology Policy. (2018). President Donald J. Trump is Working to Ensure All Americans Have Access to STEM Education [Fact sheet]. Retrieved from https://www.whitehouse.gov/briefings-statements/president-donald-j-trump-is-working-to-ensure-all-americans-have-access-to-stem-education/

Wilson, S.M. (2013). Professional development for science teachers. Science, 340(6130), 310-313.

Yoon, K.S., Duncan, T., Lee, S. W.-Y., Scarloss, B., and Shapley, K. (2007). Reviewing the evidence on how teacher professional development affects student achievement (Issues and Answers Report, REL 2007-No. 033). National Center for Education Evaluation and Regional Assistance, Regional Educational Laboratory Southwest Institute of Education Sciences, U.S. Department of Education. Washington, DC.