Zebrafish in Education

Outreach: Empowering Students and Teachers to *Fish* Outside the Box

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Abstract

The purpose of the Project BioEYES Outreach Program is to foster an enthusiasm for science education, promote interest for future participation in a biology-related field, and allow all students the opportunity to learn life science through a hands-on, student-centered approach to instruction. In the 7 years since the program's inception, we have studied our growth and impact in and out of the classroom. Our model of promoting science education through a University-K12 partnership is exemplified by Project BioEYES success in multiple cities. This effort has allowed students to perform real experiments as lead scientists in their own classrooms. The University-K12 partnership model has also provided teachers with the training and skills needed to facilitate their teaching of the experimental process by integrating complex scientific concepts into the classroom setting. Our demonstrated success with Project BioEYES in a number of large public school districts supports our effort to disseminate Project BioEYES both nationally and internationally.

Introduction

PROJECT BIOEYES, a precollege zebrafish curriculum, began with the efforts of a newly hired Assistant Professor, a borrowed microscope, and a few live zebrafish. In 2002, Dr. Steven Farber,¹ then a researcher at Thomas Jefferson University (TJU), pioneered an outreach program that utilized zebrafish from his laboratory. One of the authors (J.S.) then developed a formalized classroom curriculum and companion teacher-training program that was to be delivered to students by the teacher together with a BioEYES educator (a coteacher model). The program aligns with national and local science standards, teaches basic scientific principles, fosters critical and creative thinking, requires students effectively collaborate with peers, and introduces science- and health-related careers. From an educator's perspective, BioEYES incorporates age-appropriate pedagogy, demands efficient class management, aligns objectives and standards with achievable goals, and uses interdisciplinary approaches to foster cooperative student-centered learning experiences. Each grade-specific curriculum, correlated to the National Science Education Standards, is available on the "Teacher Entry" link on the program's website www.jefferson.edu/bioeyes.

Recent national attention has been directed to enhancing science education to promote a more informed citizenry and a globally competitive workforce.² This attention has fostered a number of Federal, state, and local initiatives^{3,4} to generate innovative curricular and instructional science education programs. The Project BioEYES curriculum is considered a model for such science reform efforts as evidenced by its growth in partnerships and ongoing support by a number of school districts. Since 2002, in partnership with the School District of Philadelphia, over 15,000 students and approximately 200 of their teachers have experienced the weeklong, hands-on, inquiry-based zebrafish curriculum. As a result of Dr. Farber's move from TJU to the Embryology Department of the Carnegie Institution for Science in Baltimore, we have gained the enthusiastic support and formalized partnerships from the Baltimore City School District and nearby Howard County and Baltimore County School Districts. During the past year, another formal partnership has been established with the University of Notre Dame (ND), offering Project BioEYES to nearby teachers. The ND initiative, unlike other Project BioEYES efforts, requires the formal participation of graduate students to deliver the program to K-12 audiences. During the first half of the 2008–2009 school year, Project BioEYES

curriculum has been experienced by approximately 122 teachers and over 2,800 students nationally. Pilot programs are currently starting up in Georgia and Valparaiso, Chile.

Materials and Methods

What is Project BioEYES?

The Project BioEYES curriculum is designed for upper elementary, middle, and high school students. At each grade level, classroom activities are created so that students solve a grade-appropriate research question. The objective of the elementary experiment (fourth and fifth) is to familiarize students with vertebrate habitats, organ functions common to humans and fish, and different cell types. Students raise larval zebrafish to observe and discuss these topics. The middle school grade experiment (sixth to eighth) deepens students' understanding of the need for medical research as well as providing a model for inheritance. At this level, research questions posed to students include, "If an *albino* female is crossed with a *wildtype* male zebrafish, will the offspring be pigmented?" The students mate fish on day 1 and subsequently observe embryo development, looking for the answer to the research question (pigmentation of the offspring). By the last day, students observe pigment production of melanocytes and discuss their understanding of dominant and recessive inheritance. The high school experiment covers aspects of Mendelian genetics. For example, at this level students may be asked, "Based on our F1 cross, what do we expect the phenotypic and genotypic ratio between *wildtype* and/or *albino* heterozygotes to *albino* homozygotes will be?" At the same time, this unit also addresses related career opportunities in the biosciences.

In all grades, topics including cell biology, life cycles, embryonic development, model organisms, reproduction, scientific methodology, and human endeavors are likely to be discussed. Project BioEYES provides these learning opportunities through the use of live zebrafish. Zebrafish are excellent teaching tools in that they are inexpensive to raise and maintain, have short life cycles, produce hundreds of offspring, and are easily transported to a classroom environment. Further, zebrafish are vertebrates, so their internal organs are similar to humans. A feature well known to zebrafish researchers is the embryo's optical clarity, which enables students to observe the embryos without harm. Further, zebrafish develop rapidly, enabling students to visualize development from a single cell to free-swimming larvae during the course of the experiment.

To help students investigate the grade-appropriate research question, each classroom receives adult zebrafish, mating tanks, food, pipettes, Petri dishes, microscopes, student journals, and development charts, costing approximately US\$5.50 per student. At the heart of the Project BioEYES program is the commitment to teacher empowerment and success that is fostered by a coteaching experience with trained university science consultants (Outreach Educators). The units all start on a Monday and run until Friday with our Outreach Educators present on days 1, 2, and 5 (1 h/class/day). The classroom teacher provides the instruction (40 min/day) on days 3 and 4. In addition, there is a user-friendly interactive website for Project BioEYES that provides an overview of the program, complete lesson plans, and where teachers and students already involved in the project can

FIG. 1. Seventh grade class at Roland Park Middle School, Baltimore.

engage in further exploration and learn about opportunities to expand their scientific studies.

On day 1, students set up mating tanks that requires the selection of adult fish from a holding tank, a discussion of related concepts (e.g., phenotype, gender, and behavior), and a recording of their hypotheses with regard to their expected experimental outcome based on specific research questions. Days 2 and 3 are spent harvesting, cleaning, and counting embryos and observing the formation and function of different structures. Determining the time of fertilization based on well-established embryo staging criterion and learning about and using a stereomicroscope are also reinforced during these days. Finally, all these activities are associated with students recording data/observations in their student journals (Figs. 1 and 2). On day 5, students can visualize red blood cells rich in hemoglobin coursing throughout the larval vasculature. Students also record the production of melanocytes, calculate offspring phenotypes, use Punnet squares, and, at the high school level, collectively determine the genotypes of parental fish. Students are asked to compare and discuss their original hypotheses with fellow students and to summarize their conclusions. Woven throughout the week are interdis-

FIG. 2. Seventh grade class at Roland Park Middle School, Baltimore.

ciplinary activities, incorporating grade-appropriate math and language arts skills, such as graphing, calculating ratios, creative writing, and designing future experiments that build on their accomplishments.

Before starting the Project BioEYES curriculum, students are given time to complete a brief (5–10 min) questionnaire comprised of multiple-choice, true/false, and Likert-scale (strongly agree to strongly disagree) statements. These questions address students' gains in content knowledge as well as the relationship of experimentation with understanding of human disease and research, and interest toward science- and health-related professions. Approximately 6–10 days later, students are asked to complete a postintervention assessment largely based on the earlier questionnaire. This later assessment also measures satisfaction with the experiment, collects qualitative open-ended responses, and provides an opportunity for students to generate comments about the program (e.g., one student wrote that he learned, "Don't be afraid of being wrong. Explore!").

How do teachers get involved?

For classroom teachers, training on this curriculum is offered as a half-day workshop held at one of our partner universities. Teachers are introduced to the curriculum by directly experiencing it firsthand, albeit in an accelerated fashion. They too formulate and seek to answer their research questions and perform a series of experimental steps. This enables teachers to discover first hand the merit of the curriculum for their own classroom while gaining the content knowledge and background to speak authoritatively on the subject. Each teacher receives a comprehensive standards-aligned manual with visual aids, pertinent background, and related classroom activity information. The teacher then schedules coteaching experiences with Project BioEYES Outreach Educators, collaborates with BioEYES staff to customize the unit for his/her individual class culture, and explores strategies to foster cooperative student research. When the university Outreach Educator arrives to the classroom, all materials, including live zebrafish, stereomicroscopes, and student consumables, are provided—in most cases, free of charge to individual schools. After completion of the professional development workshop as well as the actual classroom implementation and coteaching experience, teachers are asked to spend 5–10 min completing an electronic survey comprised of open-ended, multiple-choice, and Likert-scale statements. The first of these instruments measures workshop experiences, including laboratory setting, duration, sequence, and appropriateness of events, and perceived confidence levels, and offers open-ended requests for workshop improvement. The second of these instruments measures classroom implementation, coteaching experiences, appropriateness for class culture, readiness for self-teaching, and open-ended requests for program improvement.

Results

Exciting and educating students

Comparing pre- and poststudent questionnaires has yielded changes in both declarative knowledge (the understanding of the content) and procedural knowledge (the understanding of the process). The latest survey results were

collected and analyzed in 2008. At the upper elementary level, traditionally only 46% of students understand that their own DNA comes from their parents, but after Project BioEYES intervention, 78% students respond correctly. At the middle school level, this changes from 50% preintervention to 73% postprogram.

Other content and improvements relate to the subcellular location of DNA, fish habitats, the scientific method, and comparative anatomy. For example, only 50% of middle school respondents knew that fish did not have lungs before the experiment, whereas 86% knew after the intervention. Only 65% of high school students, mainly tenth graders, understand external fertilization preprogram versus 88% postprogram. Seventy percent of these high school students could not properly identify the egg yolk as a source of nourishment for a developing embryo, whereas only 25% missed this one postprogram.

Sadly, in schools with little resources, understanding microscopy is limited to few students before our visit as compared to more affluent schools with better equipment and, more likely, qualified educators. Because the Project BioEYES staff brings microscopes that are utilized by students for 4–5 days, offering repeated exposures throughout the week, the postsurvey reflects accurate responses about microscopes that are always in the 96–98% range postprogram.

Understanding model organisms is considered a unifying theme of biology. High school students varied in response on the characteristics of a model organism: 40% chose the correct response, but the remaining inaccurate responses were evenly chosen (20% each). Postprogram 74% of high school students properly identified model organism characteristics. One student wrote, "I learned that simple organisms such as zebrafish are good to study and experiment because they are simple, have a short life span, and produce lots of offspring." It still seems difficult for students to accept that scientists use zebrafish or any model organism to learn about human disease and medicine. Only 31% of elementary students make this connection before the program, whereas 53% of students believe this to be true after the experiment. Fifty-six percent of the middle school-level students realized this preprogram, whereas 78% realized it postprogram.

Many middle school and high school students learn the basics of heredity and Mendelian genetics before visits by Outreach Educators and engaging in the week-long experiment. Yet, only 53% of middle school students understand the basic expression of dominant and recessive alleles preprogram versus 74% postprogram. For high school students, 63% understand genotypes consist of recessive alleles, whereas 76% understand this postprogram. Some high school students commented that the most important thing they learned throughout the week was that "dominant and recessive genes determine the fish's outcome," "the genetic topic recessive and dominant genes," and "the most important thing I learned was that genetics is a very beautiful thing and is very important."

Across all grade levels students show marked improvements in their perception of science, scientific research, and science careers. For example, students are asked to respond to the following statements on their postsurvey: "Science is interesting to me," "Scientific research is important," and "I am interested in a science- or health-related career" (see Fig. 3). Fostering interest in the life science professions is part of the

FIG. 3. Average change in attitude for all grade cluster levels for statement: "Science is interesting to me" before and after BioEYES intervention.

Project BioEYES mission. Another is breaking down the stereotypes associated with scientists. "The lack of exposure students receive during their precollege education is the reason why students have such profound stereotypes of scientists and are less than enthusiastic about science's impact on society."⁵

Aside from the formalized measurements, examples of student gains are observed qualitatively through the many cards and pictures that are sent to our program postvisit. Occasional comments like "We never do science, this was great" addresses an intrinsic factor of appreciation that we believe our staff enjoys. Additionally, both staff and teachers have reported on the significance of having multiple exposures to the experimental process, materials, organisms, and instrumentation versus a 1-day activity. One teacher wrote that Project BioEYES is, "Not your standard visiting scientist program." Teachers have observed an increase in student capability and confidence when handling microscopes, organizing necessary experiment steps, and in documenting their findings. This is attributed to the belief that the 5-day program offers meaningful connections between that which was known and that which is being discovered. Teachers have reported using the student journals and data collected to serve as the basis of laboratory reports, hallway bulletin boards, or student- and teacher-constructed web pages.

Students sometimes ask questions that go beyond the standard Project BioEYES program. Many of these questions are generated during the student engagement of the week-long curriculum. In the past 3 years, we have noticed a substantial increase in the number of requests for Project BioEYES staff to assist with student science fair projects. Students use

what they have learned from the program, often designing experiments using zebrafish, to design and carry out school, city, and sometimes state science fair projects and presentations. Group and individual projects, studying concepts like the effects of tobacco or pH levels on embryo development, have garnered various accolades, including numerous student scholarships to intensive summer institutes and even to colleges and/or universities. One Philadelphia school district graduate commented during her visit to Harvard (a University with a number of zebrafish laboratories) how impressed her host was on some zebrafish facts she cited that were based on her Project BioEYES experiences.

Partnering with talented teachers

The most important school-related factor that influences student learning is teacher quality.⁶ Providing opportunities in which teachers can develop personally and professionally increases their need to be self-directed and leads to greater autonomy.⁷ Unfortunately, the urban teacher attrition rate is tragically high (>50%) during a new teacher's first 5 years.⁸ On average, 25% of Philadelphia Project BioEYES teachers have transferred annually to suburban schools, changed grade levels, and have even left to teach in other countries. During the past 3 years, new teachers have entered and many have stayed, dedicated to the Project BioEYES program. "We're engaging them in learning experiences in modern biology techniques, and they're taking to it like fish to water" (Mooney, as cited by Stowe⁹).

Several years ago, Project BioEYES staff became aware that with the growing numbers of interested teachers, and with increasing numbers of student classes, the small program would need a partner, an agent of change, and this turned out to be the classroom teacher. After 2 years of experiencing the Project BioEYES program, partnering teachers were told that lab resources were limited and demand was increasing, and that the outreach team would be exhausted if they attempted to accommodate all the teachers now expressing interest. Of those returning and participating teachers, 89% became Project BioEYES model teachers and began to self-teach the week-long experiment without the help of our in-class educators. While we still loan out equipment and mentor teachers from a distance, the classroom teachers set up adult crosses, harvest embryos, study basic embryology, and determine the genetics of zebrafish before returning the stereomicroscopes and live fish back to the research lab. "It's exciting to be able to bring something so innovative and new to the students instead of the typical things that happen in the biology class" (Alicia Harkins-Pritchett, as cited by Stowe⁹). Just a few classroom teachers at each of the three grade cluster levels who can teach the unit on their own can reach hundreds of students, an amount that would take months of staff time. Empowering teachers to learn and conduct science, independently, allows for many more students to experience Project BioEYES. Empowerment, not exhaustion, is the way to make outreach work.

Professional development workshop survey results have shown that there is an array of experience in the teachers who are participating in the Project BioEYES programs. Thirteen percent are within their first 2 years of teaching, 30% within 3–5 years, 26% within 6–9 years, 9% within 10–15 years, and 22% have been teaching between 16 and 25 years in the classroom. Seventy-four percent of teachers instruct general education

classes, 13% use the program for gifted or talented students, and 13% for special education classes. Although 100% of participating teachers felt confident on the curriculum post-workshop, and 91% were ready to coteach with university educators, only 55% percent of teachers new to Project BioEYES were ready to teach the unit autonomously. This indicates that more than one professional development session is necessary to empower teachers to integrate new curricula.

After completing the classroom unit, survey results from teachers show that they were highly receptive to the program and felt highly supported by Project BioEYES staff. Further, teachers felt that students enjoyed the program, that the program helped students connect classroom content with a live applicable experiment, and that the supplemental interdisciplinary activities were highly useful and significant.

Discussion

Classroom impact

For most students and teachers exposed to Project BioEYES curriculum, this series of laboratory activities offers both measurable and immeasurable reactions. For students, the experience has provided a “glimpse into their own bodies and a more meaningful understanding of organ systems, often generating a strong visceral reaction, unlikely to be duplicated by a video or picture” (S. Farber, personal communication). Students have reported that a highlight of the week-long program was seeing the larval heartbeat. Secondly, students experience an opportunity to apply content knowledge and use higher level thinking skills such as analysis and synthesis. The Project BioEYES curriculum utilizes real-world laboratory techniques to expose students to scientific research. Additionally, the experiments performed provide a forum for important topics that are not mandated, but important and timely, such as stem cells, cancer, and regenerative biology. The cooperative and collaborative nature of the week-long activities may also foster highly desirable team-building skills that are needed in the workforce.

Teachers have shared well-known difficulties in their instruction of topics, such as reproduction that may be somewhat particular to the United States. Despite this social milieu, the Project BioEYES curriculum fosters age-appropriate discussion of reproduction (sperm and egg, embryo, fertilization, cell division) in the context of the fish life cycle that has yet to result in a single complaint from parents. These types of connections are advocated by the *How People Learn* frameworks for science education.¹⁰ Teachers have also mentioned that students raise questions regarding the ethics of animal research during the course of the experiment. A major benefit of the Project BioEYES curriculum is that students are never asked to harm the fish and/or larvae. This curriculum is unique in its ability to address these larger issues while simultaneously covering national academic standards.

University's role in Outreach

With many exceptional curricular materials and instructional strategies now available to even the direst school districts, teachers are charged with facilitating innovative classroom experiences. The science education community, including teachers, students, scientists, product developers,

policy makers, and parents, rely on teachers to gain the confidence and competence to embrace educational enhancements. By empowering teachers, they can take charge of their own growth and acquire new skills and knowledge.¹¹ In addition, by empowering teachers with what is really a minimal amount of support (equipment, organisms, and technical support), university science departments need not expend all their energies on the growing demand for outreach efforts.

Although teachers indicate a high level of confidence on the curriculum postworkshop, only half of teachers new to program shared that they are ready to teach the unit autonomously. We feel that the coteaching experiences are a tremendous benefit to both classroom teacher and Outreach Educator and extend the collaborative experience beyond one teacher training session. Additionally, offering ongoing mentoring or technical support seems to be appreciated by teachers who may call with a last-minute question or concern before teaching. Keeping these teachers as partners in science education has allowed for their personal growth as well as for ours.

Utilizing the Project BioEYES model to bridge higher education and research institutes' school systems provides students with career opportunities in science, technology, engineering, and math and is an integral part of the program's mission. This goal of fostering science, technology, engineering, and math career exposure is exemplified by the University of Pennsylvania's commissioning of the Project BioEYES team to facilitate an undergraduate and high school mentorship program focused on regenerative biology research. Using the Project BioEYES curriculum and resources from the Institute for Regenerative Medicine, collaborative teams of local undergraduate and high school students have begun studying the topic of regenerative biology as it relates to several organisms, including zebrafish. We note that this model serves the larger goal of many University-K12 partnerships since we foresee that student research might incorporate any of the cross disciplinary sciences: chemistry, biology, environmental, and physics-related phenomenon.

Historically, funding for Project BioEYES has been local and in the small to medium size range. Each year, annual reports and proposals are submitted to offset the costs of reaching more and more teachers and their students. New partnerships have allowed our understanding of science teaching and learning to be evaluated across four states and differing school settings. It is our intention to secure Federal funding that will permit the formalized replication trials that we feel are worthy to disseminate and offer Project BioEYES training to others. We have had requests from over 12 different states and 2 foreign countries to bring the Project BioEYES to their institutions and to help form university or institute partnerships with local K-12 school districts. Project BioEYES staff travel, present 1-day or week-long professional development seminars and workshops, train new staff on preparing and coteaching the curricula, help reach out to local educational partners and funding agencies, and prepare suitable zebrafish facilities for housing, maintenance, and care of these useful animals. In addition, Project BioEYES collaborates on streamlining the collection and analysis of teacher and student feedback. Our success with Project BioEYES demonstrates that the program is ready for more widespread dissemination both nationally and internationally. For more information about how your institute can become involved

with the pre-K-12 Project BioEYES program, please visit www.jefferson.edu/bioeyes or e-mail us at bioeyes@jefferson.edu.

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