



Using urban harbors for experiential, environmental literacy: Case studies of New York and Chesapeake Bay

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ABSTRACT

Field-based, hands-on experiential learning is a mainstay of meaningful environmental science education throughout a student's school career. Engaging K-12 students in field-based, experiential learning can help develop true passion and commitment to STEM (Science, Technology, Engineering, Math) subjects, allowing students to apply their skills and content knowledge in an authentic, experiential context while enhancing many academic skills and engaging them in contextualized learning across disciplines. To develop an environmentally literate population, and to solve the increasingly complex environmental issues facing society, there is a need to increase students' access to environmental education field experiences and to connect these outdoor experiences to relevant curricula within the classroom. This is especially important in urban environments, where citizens and students may be less connected on a day-to-day basis with nature. Examples of programs in two regions that model this approach are the Billion Oyster Project-Curriculum and Community Enterprise for Restoration Science STEM-C-Project (STEM, plus computing), in New York City, and the combined efforts of the Maryland Environmental Literacy Partnership (MELP) and the NOAA Bay-Watershed Education and Training (B-WET) program, both of which focus on the Chesapeake Bay, its watershed, and Baltimore Harbor. Both regions have invested in education programs that take advantage of their harbor/waterway locations and their maritime cultures and histories. The NYC program centers around 'Oyster Restoration Stations' visited by middle-school students and citizen scientists, who use a common set of protocols and a matching digital platform interface to record data including water quality and oyster biology. The Chesapeake programs, utilize both public and private partnerships to support teachers in designing inquiry-based field investigations to support curriculum underpinning the nation's first state mandated environmental literacy requirement for high school graduation. These two regional programs provide models for implementing experiential hands-on learning in environmental science and ecology for other urban areas.

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1. Introduction

1.1. Environmental education

Human interaction in coupled human-natural systems is complex, particularly in urban environments (Liu et al., 2007). As the human population continues to grow and our environmental impacts become global in scale, promoting responsible stewardship through the creation of an environmentally literate, informed population is critically important. Environmental education can help address this need by aiming to reach all sectors of society, including students, teachers, citizen scientists, community organizations, businesses and governments, to help develop skills and understanding about global challenges in order to create a more sustainable future for the Earth (NAAEE, 2018). Common to a range of environmental education approaches is the focus on “experiential, multidisciplinary education” that develops both problem-solving and decision-making skills (Roberts, 2012; NAAEE, 2018), with a critical end-goal being the development of “environmental literacy” (Hollweg et al., 2011). Environmental literacy can be distinguished from simply having knowledge about the environment, by incorporating the ability to make environmentally sound decisions and take appropriate action (MAEOE, 2018). Environmental literacy is integral to fostering an understanding that emphasizes that humans are part of a global community and that actions and decisions made locally by individuals or communities have impacts that go well beyond local environments.

1.2. Defining environmental literacy education & establishing the need

The National Oceanographic and Atmospheric Administration (NOAA) defines an environmentally literate person as one who, “both individually and together with others, makes informed decisions concerning the environment; is willing to act on these decisions to improve the well-being of other individuals, societies, and the global environment; and participates in civic life” (NOAA, 2018). This added attention to action has become a primary feature distinguishing environmental literacy and modern approaches to environmental education in the global, ‘digital age’ from traditional approaches to education about the environment. Major goals of environmental literacy education efforts include the following: (a) development of increased awareness and motivation to act on environmental problems by the learners, and (b) a commitment to prevent and solve local and global problems

(NAAEE, 2004; UNESCO-UNEP, 1976, 1978). Inherent in environmental literacy is also the development of critical and quantitative skills that allow individuals to understand and evaluate these concepts and societal issues.

Place-based and community-based education programs typically seek to address two critical gaps in the experience of many children in a world that is increasingly both urbanized and disconnected: (1) contact with the natural world and (2) contact with community. Teaching and learning approaches that include these ideas allow the attention of young people to be extended beyond the classroom into the real world and to engage them in the process of devising solutions to social and environmental problems they face as citizens (Li, 2009; Flouri et al., 2018). This can increase both student engagement in learning of these subjects, as well as their overall academic achievement (Smith and Sobel, 2010), as research has shown that the study of the environment improves achievement in science, math, and reading (Lieberman and Hoody, 1998). In addition to enhancing students’ academic performance across many subject areas, place-based learning can also improve pupils’ concentration and confidence, and ultimately their mental health (Strife and Downey, 2009; Jenkins, 2016), including increased engagement and enthusiasm for learning, and positive impacts on students’ physical, cognitive, and social development (Burdette and Whitaker, 2005). This approach has the potential to provide tangible education benefits for individual students, as well as community and societal benefits resulting from improved environmental stewardship.

Contact with the non-built environment and nature is increasingly important in our modern digital age when children are likely spending more time inside interacting with electronic devices than they are playing outside (Hofferth and Sandberg, 2001; Hofferth and Curtin, 2006). The importance of outdoor experiences for students is well-documented (reviewed in Strife and Downey, 2009) and a concern that children’s opportunities for such experiences were decreasing sparked the concept of ‘leave no child inside’, responding to and mirroring the education initiative “no child left behind” (APHA, 2007; Frumkin and Louv, 2007; Louv, 2007; St. George, 2007). Children’s early experiences and contact with nature can affect their future interest and concern for environmental issues, with Strife and Downey (2009, p. 101) stating: “research has...shown that regardless of race, ethnicity, and socioeconomic status, early childhood experiences in nature significantly influence the development of lifelong environmental attitudes and values” (Strife and Downey, 2009 and references therein). Consequently, parents, educators and other community members have become concerned that society’s increasingly ‘de-natured children’ (Strife and Downey, 2009) – who are isolated within built environments that are in turn becoming more urbanized – will not have the same environmental ethos and concern

needed to protect the environment in a challenging future (White, 2004; Louv, 2007).

Climate change, species extinctions, range-shifts of disease-causing organisms, invasive species introduction through global shipping, human population growth, increased food production and other complex, 'wicked' environmental issues (Rittel and Webber, 1973; Head, 2008) of global significance will be among the challenges faced by the current generation of K-12 students. These students are also arguably the first generation to grow up immersed in digital technology. By harnessing the aptitude of these cyber-savvy students for digital technology, while engaging them in environmental education programs that are place-based and relevant to their local community, we may help pique the interest of a new generation of 'digital native' (Bennett et al., 2008), science students in a transformative manner. To meet the challenges of the Anthropocene (Steffen et al., 2007), we must be addressing environmental literacy through education programs that stress research and problem-solving initiatives in increasingly urban and impacted settings.

1.3. Experiential learning in schools to improve environmental literacy

In the context of schools and schooling, the action-oriented goals for environmental literacy education often demand a more active, situated approach to instruction. A key philosophical model that can meet these needs is experiential learning. Drawn from the work of Dewey, Lewin, Piaget, and others, this philosophy views learning as a dialectical process which integrates concrete, personal experiences with reflection, consideration, and application (action) (Itin, 1997, 1999; Kolb, 1984; Kolb and Kolb, 2005; Beard and Wilson, 2013; AEE, 2018). Experiential learning is distinguished from traditional approaches in that learning constitutes a process – where “concepts are derived from and continuously modified by experience” (Kolb, 1984, p. 26) – rather than the accumulation of a fixed set of ideas or outcomes.

Experiential learning in a school context makes use of multiple relationships: between the educator and student, the student and their environment; the student and their own reflective understandings, and the student and their peers collaborating in a group setting. Learning in this sense is initially stimulated by experiences, but then nurtured and furthered by a student's reflections, analyses and synthesis of concepts. Successful experiential learning occurs when students take initiative and actively participate in their learning by posing questions and integrating knowledge to solve problems in a creative way (e.g., Itin, 1997, 1999), thus constructing their own knowledge and achieving higher-order cognitive outcomes (Bloom et al., 1956; Anderson and Krathwohl, 2001). Further, experiential learning is augmented when disciplinary content is applied in authentic contexts and can therefore be 'tested' against relevant real-world problems with opportunities for reflection and refinement (e.g. Knobloch, 2003; Lombardi, 2007).

Experiential learning models work to support the sense-making and understanding required for environmental literacy and student achievement by connecting relevant academic content to life-relevant, place-based and community-based issues and phenomena that may be investigated through collaborative participation in disciplinary practices and meaningful reflection. Such activity represents a response to the frequently-asserted reformist concern that “students should be engaged in the activities of historians, mathematicians, scientists, or literary analysts rather than just learning about the results of those practices” (Ford and Forman, 2006, p.1). These approaches further align more closely with the constructivist theoretical commitment that learning is not a result of direct transmission from one knower

to another, but rather is actively constructed through individual and social processes (Driver et al., 1994; Bransford et al., 2000), allowing students to become active agents in the processes of constructing and justifying knowledge, thus strengthening the learning required for academic achievement.

By situating learning experiences in authentic, real-world contexts – many of which are most productively explored outdoors, *in situ* – experiential approaches allow students to more easily see the value of content, activities, and academic tasks by connecting discrete facts and data to situations that are meaningful to themselves and their communities. These contextualized learning experiences allow students to form connections between prior knowledge and new ideas, transfer and apply information across multiple contexts, and develop deep conceptual understandings that are critical for academic achievement and success. Thus, environmental literacy-driven experiential learning practices can increase students' engagement with learning of disciplinary content while also enhancing their overall academic achievement (Kolb, 1984; Kolb and Kolb, 2005; AEE, 2018).

1.4. Embracing environmental literacy in an increasingly urban global population

The need for educational experiences that work to improve environmental literacy is compounded by increased urbanization. As of 2018, 55% of the world's population lived in urban areas, with a projected increase to 68% by 2050 (United Nations, 2018). In the United States that percentage is even higher, with 82% of the population being categorized as 'urban' (World Bank, 2018). Large cities have historically developed along coasts for transportation and trade purposes as well as within coastal regions that were naturally productive, with available freshwater and food resources adjacent to naturally protected harbors. Coastal marine systems, at the confluence of fresh and marine water, terrestrial inputs and shallow sedimentary settings, play fundamental roles in the life cycles of many open ocean species. Thus, the future resilience of the global marine environment critically depends on the use and sustainability of increasingly urban marine systems (Chawla, 2001; Beatley, 2010; Niemelä et al., 2011).

Since the advent of the mercantilist period of capitalist development, urban harbors have represented an important point of intersection between built and natural environments. Coastal populations harvested the resources of their harbors, used them for shipment and transportation, and dumped waste into them with little concern for the impacts on marine biomes. Today, around 90% of all commercial products pass through harbors worldwide and around half of the world's population lives within 100 km of the coast (UNEP, 2016; Steinberg et al., 2016). Modern production has added agricultural and industrial effluents and solid waste, including plastics, to harbor dumping (Steinberg et al., 2016). Perhaps, because the marine biome is largely invisible, or because harbors are so intensely industrialized, cultural attitudes toward harbor environments have remained stubbornly utilitarian, even as support has grown for wilderness areas and conservation in the terrestrial countryside (Steinberg et al., 2016; Satterfield et al., 2018).

The obvious degradation of natural habitats reached a critical point in the 1970s, which saw the beginning of the environmental movement that has slowly changed the population's perception and appreciation of their urban waterways (Sekovski et al., 2012). As a result, over the last few decades, we have seen an increase in accessibility and recreational activities on these urban waterways and many cities are reclaiming access to their harbors, rivers, and creeks (Healthy Waterways, 1998; Boicourt et al., 2016; O'Neil et al., 2016). With these changes has come the recognition that

these waterways are not devoid of life, and can still be diverse and productive habitats (Levinton and Waldman, 2006). However, to help preserve, improve and protect these environments, we need to educate the local populations and foster efforts to improve and/or maintain the health or quality of waterways in their regions. It is thus vitally important to school students that they, as members in a wider informed citizenry, develop local connections to their environments beyond the built environment around which the majority of their daily lives usually revolve. Consequently, experiential learning models may be even more important in urban environments by offering ways for young people's attention to be extended beyond the classroom to their local environment (NEEF, 2015). The exploration of environmental issues in students' local urban harbors and waterways, therefore, provides a focal point to help to engage students in the process of devising solutions to the social and environmental problems they face as citizens and helps them engage in community activity. When students are encouraged to "take ownership" of their learning and have the freedom to make decisions in problem-solving, it is very empowering to them (Jenkins, 2016).

1.5. Global need for environmental education integration into classroom curriculum

The global nature of environmental problems such as climate change, population growth, and unsustainable development, has led many international and national organizations to advocate for the strengthening of goals for environmental literacy (UNESCO, 2010; NEEF, 2015). Disciplinary content related to the environment is an integral part of K-12 curricula across the United States; however, researchers have expressed the need for schools to go beyond merely teaching about the environment and to promote environmental stewardship by educating students about anthropogenic impacts and possible solutions. Issues-based, group projects can help develop a sense of community and place-based knowledge in students (e.g. DeWaters and Powers, 2006). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, the foundation for the *Next Generation Science Standards* (NGSS) designed by multiple states in the US and released in 2013, typically emphasizes project-based and active, experiential learning (Bestelmeyer et al., 2015), extending core disciplinary concepts with information on human impacts and advocacy for action (NRC, 2012). In addition, many US states are developing comprehensive environmental literacy plans for K-12 curriculum. Maryland, for example, is the first state in the United States to include environmental literacy as a requirement for high school graduation. Furthermore, Maryland has established a set of Environmental Literacy Standards, which include environmental issue investigations and student action components (MSDE, 2018).

Baltimore and New York City are two of the original large port-cities on the east coast of the United States; each has played a major role in the history, culture, commerce and economics of the country and both are partner cities in the World Harbour Project, and international partnership which aims to link, facilitate, and enhance programs of research and management across major urban harbors of the world (Steinberg et al., 2016; O'Neil et al., 2016; WHP, 2016). Both regions have invested in STEM education programs that take advantage of their harbor, waterway locations and maritime history. This paper highlights programs in these two regions in experiential, hands-on education, that utilize their urban harbors and surrounding waterways to promote environmental science and STEM-C literacy. Both regional programs emphasize participation in authentic research projects and place-based investigation which engage and inform not only students across multiple age groups, but community and citizen-scientist groups, to inspire civic action and help to achieve an environmentally-literate and informed population.

2. Case studies

2.1. New York Harbor Case Study: Billion Oyster Project and the Curriculum and Community Enterprise for Restoration Sciences (BOP-CCERS)

The Billion Oyster Project (BOP), founded in 2014, is an education, environmental research, and marine ecology restoration initiative in New York Harbor and the lower Hudson estuary (BOP, 2019). It grew out of the experiential pedagogy of the Urban Assembly New York Harbor School (Harbor School) and its allied non-profit, the New York Harbor Foundation (NYHS, 2019). The Harbor School's STEM pedagogy has always emphasized hands-on, experiential learning, as represented in its mandatory environmental field science course and its several Career and Technical Education (CTE) tracks, which include aquaculture, commercial diving, ocean engineering and ocean piloting. In 2010 the school moved from Bushwick (in central Brooklyn) to Governors Island (between Brooklyn, Manhattan and Staten Island), where a retired Coast Guard hospital and pier were refurbished to house the school and the foundation. On Governors Island, they were able to establish research and restoration infrastructure, including a fleet of boats, SCUBA gear, algae and fish-growth tanks, an Ocean Engineering lab, and an oyster breeding facility.

New York Harbor is situated within a large estuary where the combined watersheds of the Hudson, Raritan, Hackensack, Passaic and Bronx Rivers, flow into the Atlantic Ocean (Fig. 1). The harbor watershed covers more than 17,000 square miles, spanning four states, with a population of ~20 million people. One of the largest, well-protected natural harbors in the world, the Hudson River estuary has supported human populations continuously for at least the past 3000 years. After European colonization about 400 years ago, its population grew dramatically as it became a major trading, commercial and industrial center. The Harbor has been central in the growth and development of the culture and economy of New York City (O'Neil et al., 2016). The Hudson/Raritan estuary was, at the time of European colonization, one of the planet's most biologically productive and resilient ecosystems, supporting at least 250 species of fish (Waldman, 1999). A cornerstone of that ecology was the incredibly abundant Eastern oyster, *Crassostrea virginica* (Kurlansky, 2006; Waldman, 1999). The historical extent of oysters in New York Harbor has been estimated at approximately 200 square miles of 3-dimensional reef structure, which would have contained hundreds of billions of individuals, making the oyster the original ecosystem engineer of New York Harbor (Kurlansky, 2006). These reefs stretched from the entrance of the harbor off Staten Island northward to the northern end of the widest section of the River, Haverstraw Bay, approximately 56 km (35 mi) north of New York City, which marks the upstream, northern boundary of lower Hudson River estuary.

Archeological evidence indicates that oysters were utilized by Native North Americans, likely the antecedents of the Lenape people at least 6000 years ago (Classen, 1995). In addition to food, oyster reefs provided: (a) attenuation of waves, (b) filtering of plankton, nutrients and sediment, and (c) complex three-dimensional habitat for associated marine life, making *C. virginica* a keystone species. Abundances of the Eastern Oyster declined throughout the ecosystem in the 19th and 20th century. This decline can be attributed to overfishing and loss of habitat resulting from marshes and coastal areas being filled in to increase Manhattan's land-area, and the development of a working waterfront to support shipping and the demands of growing economy. Additionally, there was also an increase in the deposition of waste materials into the waterways, contaminating any remaining oysters, with the closure of the last commercial beds in 1927



Fig. 1. Hudson-Raritan River Estuary, New York Harbor and surrounding tributaries and waterways, and watershed of the Hudson River system. New York Harbor is one of the partners in the World Harbour Program (WHP, 2016).

(Waldman, 1999; Kurlansky, 2006)). Therefore, to their central role as keystone, ecosystem engineers, any large-scale restoration plan for the region must begin with attempting to bring back the oyster reefs and their associated communities. The BOP has undertaken that task and, together with the Harbor School and collaborating scientists, educators, and citizen-science volunteers, have made the restoration of oysters and oyster reefs the central focus of a broad educational effort in the New York and lower Hudson Valley region.

Even before the founding of the BOP, the NY Harbor Foundation engaged high school students from the Harbor School in restoration and marine research, working with their teachers and the staff of the NY Harbor Foundation. With the BOP, the effort has attracted new volunteers: teachers from other schools and their classes, and citizen-scientists motivated by a desire to see New York Harbor return to some of its prior biological diversity. In 2013, in a significant expansion of its educational efforts in the Harbor, the NY Harbor Foundation organized a team of academic and informal education partners to submit a proposal to the National Science Foundation (NSF) to fund a 'Curriculum and Community Enterprise for Restoration Science' (CCERS). The CCERS targeted public middle schools serving predominantly Title I (low income) families. In part, the audience was chosen because literature indicates that middle school is a critical age in which to engage children's interest in science. It was also intended to build a pipeline of students from groups under-represented in STEM applying to the Harbor School (Ainley and Ainley, 2011).

The central partners in the CCERS included the NY Harbor Foundation, which provided the overall vision for the project as well as expertise in environmental and ecological curriculum and experiential learning, Pace University, which hosted professional development (PD) for in-service middle school science teachers and managed the project; Columbia University, which provided science and science curriculum expertise; the University of Maryland Center for Environmental Science, which provided science and educational expertise and managed development of software for a BOP digital platform; and the New York Academy

of Sciences, which implemented an after-school program delivering BOP-related content through Good Shepherd Services and its contract with New York City. In addition, the CCERS worked with informal education organizations: The River Project, which houses a hands-on, experiential learning site on the Hudson River; The BioBus, which at the time was operating in the Lower East Side Girls' Club, and assisted in development and testing of the CCERS field protocols; and the New York Aquarium, which was unable to participate during the CCERS grant (due to damage from Hurricane Sandy), but designed a hands-on exhibit on coastal ecology, including an oyster reef touch tank, scheduled to open in 2019. Participation of the New York City Department of Education was critical to recruiting teachers and facilitating access to their schools and classrooms. Two external evaluators were engaged, Gaylen Moore Associates, who implemented and reported on all the evaluative instruments (Moore and Thomas, 2018), and SmartStart Evaluation and Research, which studied the project per se, and assisted in publicizing project outputs (Molina et al., 2016; Watson et al., 2018).

The BOP-CCERS Model was implemented through five education-resource pillars: (1) a teacher training fellowship; (2) student curriculum and field science; (3) digital platform development; (4) afterschool and summer mentoring, and (5) community engagement/restoration based aquarium exhibits (Fig. 2). The five pillars were designed to provide multi-faceted programs to "wrap-around" the student, including classroom instruction, field science, after-school programs and engagement with the student's community (Newton et al., 2015; Birney, 2017). In practice, the "wrap-around" strategy did not prove completely workable. For instance, it was not practical, within the scope of the project, to ensure that schools with CCERS teachers also had after-school and summer programs provided by our partners; therefore Pillar 4 proceeded independently, and is not discussed here. All the community outreach planned for Pillar 5 including the restoration-based aquarium exhibits, surrounding the CCERS schools was also not realistic in the 3-year scope of the grant since it would have required the school programming to stabilize

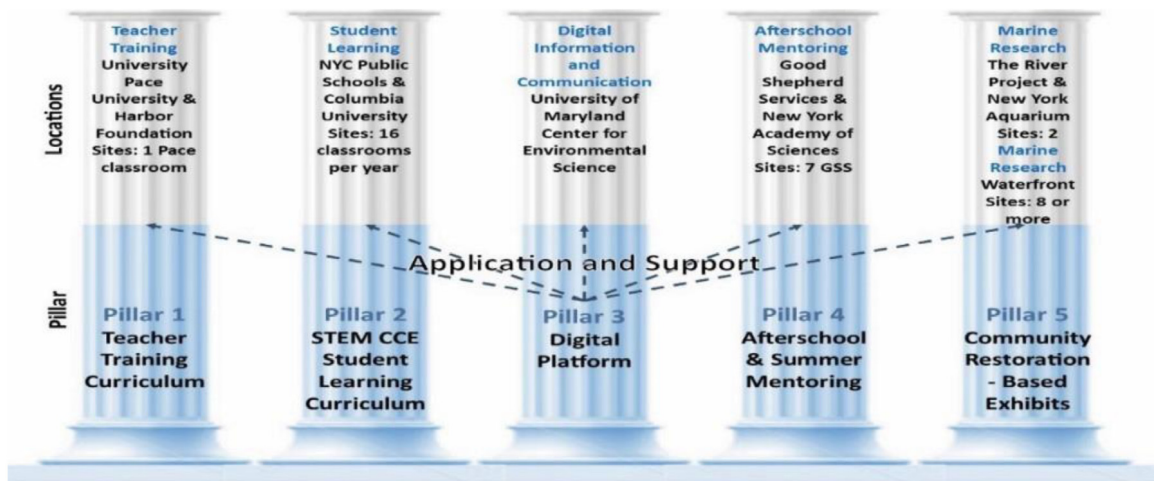


Fig. 2. Billion Oyster Project-Curriculum and Community Enterprise for Restoration Science (BOP-CCERS) model for the STEM-C-Project in New York City (NYC) Public Schools which consisted of five education-resource pillars that functioned in combination as well as independently to support middle school student learning and teacher training in five distinct, but collaborative areas.

first. This meant that, in practice, Pillar 5 focused exclusively on informal education at The River Project (Caref et al., 2018) in support of Pillars I and II, the teacher professional development and implementation of a harbor-based curriculum.

The River Project provided an extremely useful venue for teacher training and class trips. A community-based exhibit of life in the Hudson River, The River Project is located on a pier in the Hudson River and is equipped with large flow-through tanks and laboratory benches with microscopes, where students can also get their hands wet and dirty with Hudson River wildlife (Caref et al., 2018). One of the most important aspects of The River Project field trips has been to “dispel the dead river myth” (Caref et al., 2018), which is a notion that the waterways are so polluted that aquatic life cannot be supported. The exhibits also help educate the general public on the shared benefits of restoration efforts in improving the environment for all. This helps to generate an environmentally informed and literate citizenry and spur a reconnection and interest in the ecology of the harbor that has been underutilized for education purposes (Caref et al., 2018).

The New York Aquarium was not able to recover from Superstorm Sandy damage in time to collaborate with the other pillars. However, as part of the project, a coastal exhibit featuring oysters, oyster reefs and oyster restoration as well as educational space, including interactive, inquiry-based exhibits will be open to the public in 2019. This will expand the reach of the project, and knowledge of oyster restoration and the ecology of the waterways, to include the hundreds of thousand of visitors and the tens of thousand of students that participate in the NY Aquarium's education programs. Therefore, the focus of further discussion here, will be limited to Pillars 1, 2 and 3 (Fig. 2).

As part of Pillar 1, teaching fellows, all of whom were in-service public middle school science teachers, received graduate credit and/or stipends for participating in approximately 18 evening professional development (PD) workshops and several days of field training on weekends, ‘professional’ days, or during summer. The PD workshops prepared middle-school teachers in developing and implementing a new curriculum that integrated restoration science into classroom lessons. During the period of the CCERS, each PD workshop included an hour of science content and an hour of pedagogical training, a format that evolved over the course of the NSF grant. In its third year, a workshop structure was settled on, that was comprised of a short lecture from a local scientist involved in relevant research on the physical, biological or ecological environment, followed by a hands-on or minds-on

activity co-designed by the visiting scientist, CCERS science leads, and CCERS curriculum specialists, and a pedagogical methods lesson led by educators from The Harbor School. Each PD ended with a short evaluation instrument.

The goal of the teacher professional development training program with the BOP-CCERS was to have teachers shift their pedagogy toward techniques that motivate students through long-term inquiry-based projects that center on solutions-based activities addressing real-world problems (Krajcik et al., 1994; Denison and Oliver, 2013; Watson et al., 2018). The PD also incorporated Bybee's 5E Instructional Model (Bybee et al., 2006), which describes student experiential learning as a sequence—engage, explore, explain, elaborate, evaluate. In keeping with Kolb (1984) and other experiential education concepts, Bybee's model describes a process by which learners build their conceptual understanding across time, using their foundation knowledge coming into the program. Throughout the program, students were encouraged to ‘act like scientists’, engaging their prior knowledge in the context of environmental restoration, which allowed them to explore new concepts, explain the connection between concepts and subject areas, elaborate on those new understandings, and evaluate their understanding (Bybee et al., 2006).

The second pillar of the project – STEM CCE Student Learning Curriculum – was based on the premise that project-based learning enhances student engagement when activities encompass real-life problems (e.g., (David, 2008)). Students established a monitoring site at the waterfront near their school and engaged in active monitoring of field conditions there. Classes deployed ‘Oyster Restoration Stations’ (ORS, recently renamed Oyster Research Stations) (Fig. 3D). The ORS design combined an oyster cage developed by the NY Harbor School's aquaculture program with a shoreline monitoring device developed for the Environmental Protection Agency (EPA) by CCERS collaborators from Columbia University (Reid et al., 2015). The ORS consists of a cage housing live oysters, a trap for mobile organisms and settlement tiles to attract sediment and sessile organisms, in a package designed to be easily retrieved and redeployed, and to be resilient in a high-energy built shoreline setting (Fig. 3).

Each participating class monitored field conditions at least twice per semester using a set of five protocols: (a) Site conditions; (b) Oyster measurements; (c) Mobile traps; (d) Settlement tiles and (e) Water quality parameters. These protocols were outlined in a handbook created specifically for the project

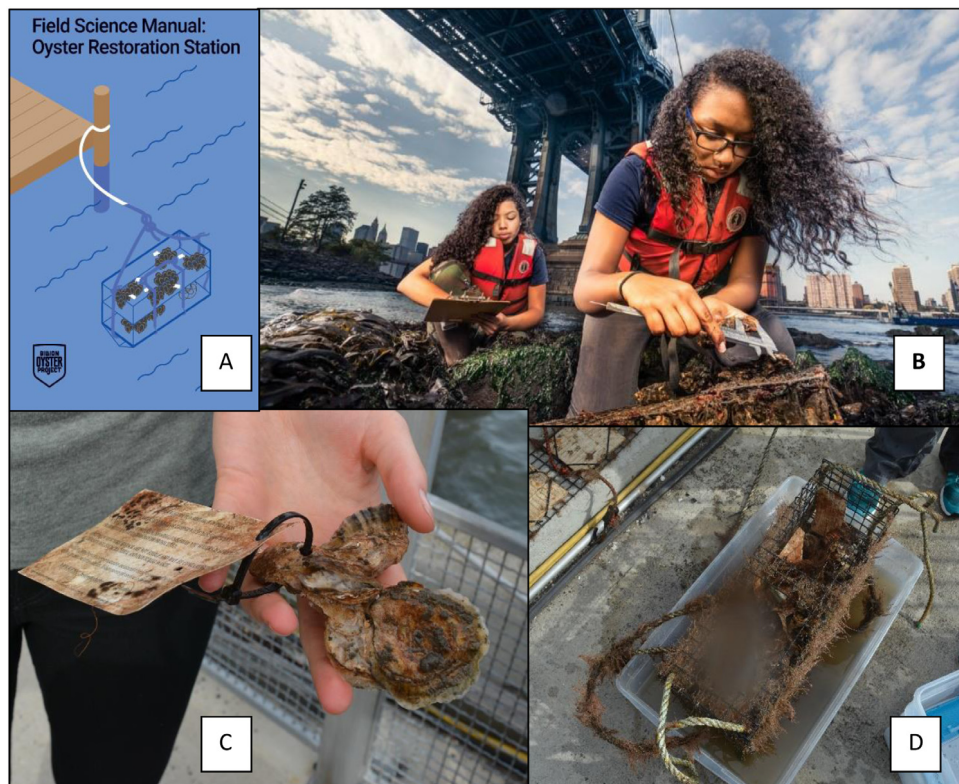


Fig. 3. (A) Oyster Restoration Station (ORS) Field Manual created for project (Janis et al., 2016; <https://billionoysterproject.org/restoration-station/>); (B). NYC students recording data from an ORS (Smart Start 2018; Photo credit: Billion Oyster Project); (C) Oyster spat on shell from ORS; (D) ORS set-up demonstration at Governor's Island Sept 2017 (C&D photos: J. O'Neil).

(Fig. 3A). The students tracked their collected data using a supported platform (see next section) and compiled them for end-of-year final projects that included presentations at an annual STEM-Symposium at the NY Harbor School on Governors Island. The guided-inquiry approach of learning and shared discovery taken by students and their teachers in monitoring field conditions in this way align with the Next Generation Science Standards (NGSS), which stress a deeper, multi-dimensional understanding of concepts rather than the memorization of facts (Marx et al., 2004).

The third pillar of the BOP-CCERS project was the development of a Digital Platform, with the goal of supporting the data interpretation, communication and development of computer skills from the first two pillars. Initially, a mobile application was created and trialed that had students collect data on notebook-touchpads, which were provided, or mobile phones, but this proved more problematic than useful to the teachers. It became evident that it would be more practical for teachers to have students record data on clipboards with paper data sheets, and to transfer these data to a laptop or desktop computer following the field visit for further use in the classroom (see section below for further details). Therefore, after the first season, the mobile app was discontinued and the focus shifted to the development of an online digital platform, fit-for purpose, that incorporated field protocols and records, curriculum resources and a portal for communication between teachers (BOP, 2018). The teacher portal, and a data collection application were completed in time for the second and third (of three) cohorts. The server-side applications (the digital platform) were completed after the end of the CCERS grant, and are being implemented as part of the ongoing Billion Oyster Project, but not in time to be fully evaluated as part of the CCERS. The digital platform is currently operational and is part of the permanent infrastructure of the ongoing BOP (Fig. 4).

The platform houses lessons and class-modules with notes and tips on how to implement, as well as notes on how lessons can be aligned with the NGSS standards. It provides an archive of all BOP data, including measurements made by the CCERS classes. The ultimate goal, although not yet fully implemented, is to allow middle-school students, along with the citizen scientists and others who participated in oyster restoration or shoreline monitoring activities, to be able to share and visualize data across school and community sites (Janis et al., 2016; Birney et al., 2016; Birney, 2017), as well as be able to compare to historic water quality trends in NYC Harbor (Taillie et al., 2019).

2.2. BOP-CCERS outcomes

After 4 years the BOP-CCERS project has established a lasting network that includes approximately 60 teachers at approximately 50 middle schools, teaching approximately 4000 students representing all 5 NYC boroughs. The CCERS teachers and students deployed and monitored approximately 70 ORSs at about 35 sites over the 4 years of the project. An equivalent number of ORSs and sites have been deployed by citizen scientists and schools not participating in the CCERS, for a total of 190 ORSs at 67 sites around the harbor (including both CCERS and non-CCERS sites) actively supporting the program of oyster restoration by the end of 2018. In this regard, the program is a true benefit as an environmental education and outreach tool, that actively engages participants in experiential learning.

From its inception, the BOP has embodied the true integration of marine ecological restoration with education. At this point, we see the success as an education program, but its success as a restoration project is to date, uncertain. Students use ORSs to measure the establishment of invertebrate communities and the growth, or mortality, rates of oysters, but ORSs are not restoration



Fig. 4. A screen shot from the Billion Oyster Project-Curriculum and Community Enterprise (BOP-CCERS) digital platform showing the current status of users associated with the program and information uploaded to the platform, located at: <https://platform.bop.nyc/restoration> [Date accessed 27 Nov 2018.] The digital platform created for the BOP-CCERS program serves several purposes: (1) To provide a platform for students and citizen scientists to record their data from the Oyster Restoration stations; (2) for teachers to share curriculum modules and resources; (3) for students to post their research results in the form of poster or papers; (4) For communication of events, workshops and student symposia for the community (<https://platform.bop.nyc/restoration>).

sites per se, and will never grow into oyster reefs. The BOP has attempted restoration at a total of 15 sites, of which 12 are still active. After 5 years of deploying oyster shell packages and seeding them with juveniles, a total of 1 acre of oyster reef is actively reproducing. This is, on the one hand, a tremendous success: it means that New York Harbor waters are clean enough, and that the levels of disease and predation are low enough, that oysters can survive in the modern harbor, and that these live oysters will be providing ecosystem services, such as water filtration. On the other hand, if the rate of reef establishment were to stay at current levels, the project would have to continue for thousands of years just to restore a couple of percent of the pre-industrial distribution. The hope, clearly, is that non-linear acceleration of oyster bedding will occur as we reestablish reef environments.

It has been possible to measure educational outcomes for the 60 teachers participating in the 3 CCERS cohorts (Moore and Thomas, 2018). CCERS goals were the following:

- (1) Increase teachers' capacity to manage hands-on, outdoor, experiential learning, including both the knowledge base and pedagogical skills required to work with students on shoreline projects;
- (2) Increase quality and effectiveness of STEM-C classroom teaching and learning; and
- (3) Increase public middle school students' knowledge of and interest in STEM.

Teachers completed evaluation forms after each PD and were evaluated on subject-matter content near the beginning and end of their PD cycles. They also completed surveys regarding their experiences and opinions about the program and its efficacy. A small subset of students was also surveyed on subject matter content and attitudinal shifts before and after their participation (Moore and Thomas, 2018). Major outcomes are summarized below:

- Teachers entered the program with major gaps in content knowledge. One of the major deficiencies, surprisingly, was an extremely low level of knowledge about the geography of New York City and its waterways. There were significant improvements in teachers' subject matter and skills knowledge in nearly all subjects covered.

- Teachers reported a significant increase in their ability to implement hands-on, outdoor, experiential learning strategies.
- Over half of teachers reported that they are continuing to implement the BOP shoreline protocols after the end of the CCERS program support.
- The principal reason cited among teachers for continuing with the BOP was student enthusiasm and engagement.

Student results were more ambiguous.

- Students showed subject-matter learning that was statistically better than their peers in control groups, but the gains were typically modest (a few percent on subject tests).
- Students showed significant improvements in engagement and enthusiasm.
- Students showed no increased interest in science as a career.

The CCERS team also had direct contact with approximately 300 of the participating students each spring at a BOP Science Symposium on Governors Island, at the NY Harbor School. Reports from the team were universally positive—in most cases superlatively so.

The overall impression derived from direct contacts and from a review of the evaluative results, is the following:

- The BOP-CCERS program has worked well to introduce a linked field-and-classroom science curriculum based on harbor restoration;
- Teachers are able to learn the required subject matter content and skills, and more than half are enthusiastic about changing their pedagogical style; but that:
- Shifting pedagogy in the schools to where results are strong and visible among students will take more than 3 or 4 years. And,
- The first positive signs of change are in student engagement with the harbor, with field science and with authentic data.

Along with the successes of this program, there were, with all projects, also areas where improvements could have been made. The somewhat limited progress of the program against all of its original goals was primarily a function of limited time. Changing

the educational practice at a school requires training teachers, getting administrator support, changing schedules, re-orienting parent and student expectations, and integrating new practices into the shared culture of all stakeholders at a school (students, teachers, parents and administrators). In that light, the 2-year engagement of teachers with the program can only be seen as the beginning of a longer-term process. The results of the evaluation that half of the teachers were willing to continue to roll out the BOP curriculum in the absence of program support and funding should be seen as a rather high rate of acceptance. Improvements in engagement are high priority goals at this early stage of implementation of a novel curriculum.

In terms of the seeming lack of shift in career goals for students is likely to be expected for a program as short-lived as this one. Students' aspirations are set in a broad context that includes the culture of the school, peers, parents and the wider social setting. Experience has indicated with other educational programming, that it realistically takes between 5 and 10 years for a novel pedagogy to shift the culture of a school, which is essentially what would be needed to change how students view their future selves. This program was also limited by changes made to accommodate limited funding. In the initial 5-year project proposal, there was a 1-year program initiation set aside for curriculum and technological development. The actual funding only allowed for a 3-year program, which led the program management to attempt curriculum and application development in parallel to training the first cohort of teachers. The initial curriculum development strategy aimed for teachers to play a large role in writing modules, which would be refined through a group process managed by a curriculum specialist. In practice, it was unrealistic to expect the teaching fellows to play a significant role, given their lack of experience with hands-on field- and lab-based curriculum and with the specific curricular content of oyster ecology and restoration. This meant that the first teacher cohort and, to some extent the second, had limited material to work with in the classroom.

There were several challenges with the development of the digital-platform in terms of scope and time as well. The project management initially had little application development experience, and a first attempt faltered due to problems in communication and coordination between the users and developers. Improvements were made, and a functional system was finally created, but many solutions came too late for the three cohorts that are reported on here. Some improvements that could have been made, would have been to drastically simplify the application development, and to have relied more heavily on commercially available software. Additionally, assembling an experienced curriculum development team a year ahead of our first cohort, so that Fellows could begin by adapting an existing set of modules, would also have proved very useful.

A few other improvements could have been a greater focus on metrics assessing student engagement, and implementing the flexible training curriculum for teachers that was finally established by the end of the project. The most fundamental lesson is that implementing change on this level requires more time. A three-year grant was, based on this experience, sufficient for the program team to come to grips with the problems of this scale of implementation, to develop a curriculum development methodology and a core set of modules, and to create the technical infrastructure necessary to support experiential learning in the field. This amounts to a very good beginning, and hopefully these are foundations which will continue to be built upon.

2.3. Baltimore Harbor–Chesapeake Bay Case Study: Maryland Environmental Literacy Partnership and Watershed Education

The Chesapeake Bay, the largest estuary in the United States, serves as a 200 mile long protected corridor that leads to the entrance of the Port of Baltimore. Similar to New York Harbor, the Chesapeake Bay and Baltimore Harbor were central to the growth of culture, economic and urban development of the East Coast of the United States. The port of Baltimore has been central to the nation's commerce since the 1700s when it grew from a small tobacco trading town to a major shipping port for flour and textiles, and eventually ship building. The city went through explosive growth from the mid-1700s through the early 1800s (City of Baltimore, 2006), with Baltimore becoming the fastest growing city in the country by the late 1820s. The population increased dramatically over the next century, and similar to New York City, marshes and waterfront were filled in to create more land around the harbor. Industrialization in Baltimore, farming in the Chesapeake tributaries and its extensive watershed (Fig. 5), along with population growth, fostered anthropogenic eutrophication in the waterways throughout the 19th and 20th centuries. After approximately one hundred years of decline in Baltimore Harbor and the Chesapeake Bay, the region is currently now seeing significant trends in improvement in ecosystem health (Orth et al., 2017; Lefcheck et al., 2018). In part, this improvement is due to the public awareness and the deep economic and cultural connection and societal value that the community places on the Chesapeake Bay and its surrounding waterways. There is a long history and pride of place for people of the region, especially for residents bordering the Bay in the states of Virginia and Maryland, as well as the residents of the City of Baltimore. The trends towards improvement are moving in the right direction in many areas, but there is still much work that needs to be done in terms of ecosystem restoration goals, especially in the more impacted regions such as Baltimore Harbor.

2.4. High school environmental literacy requirement

Given the deep environmental connection and cultural identity with the Chesapeake Bay waterways and wildlife in the region, as well as the central role they play in the economy of the region, it is not surprising, therefore, that Maryland became the first state in the nation to establish an "environmental literacy requirement" for high school graduation. In 2011, this became part of the Code of Maryland Regulations (COMAR), the official compilation of all state agency-issued administrative regulations, that provide policy guidance for local school systems (COMAR, 2018). This landmark step, based on a sustained history of environmental education initiatives in Maryland, grew out of long-term efforts from multiple public and private entities. These included several pivotal programs, including the creation by Congress in 2002 of the NOAA B-WET Program (described in more detail below) and the 2008 creation of the Maryland Partnership for Children in Nature (now Project Green Classrooms), by an executive order by the Governor of Maryland (Executive order 01.01.2008.06; <http://mdrules.elaws.us/comar/01.01.2008.10>).

These government initiatives were meant to garner support from other state and local agencies to advance student environmental literacy, informed citizenship, and stewardship through meaningful watershed educational experiences and to support outdoor learning connected to and supportive of classroom learning. This helped to build a coalition of ongoing support for these endeavors. The objective was to "integrate environmental education into the K-12 curriculum giving teachers and students new opportunities to take learning outside; explore their communities; analyze issues; learn about connections between the

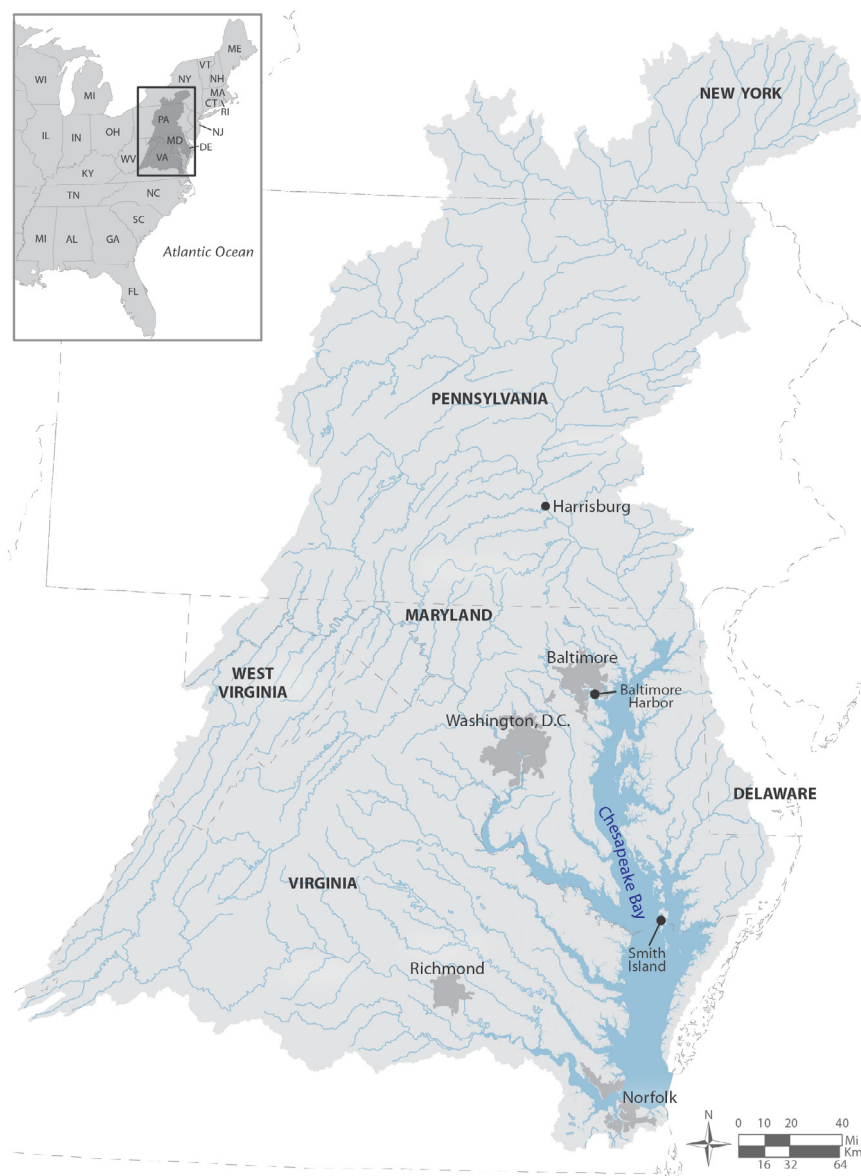


Fig. 5. The Chesapeake Bay Watershed extends hundreds of miles into New York State and encompasses the jurisdiction of 6 states and the nation's capital, Washington, District of Columbia; Baltimore Harbor at the head of the Chesapeake Bay is one of the partner cities in the World Harbour Project (WHP, 2016).

economy, society, and environment; support economic growth; and become engaged citizens" (NAAEE, 2014). These efforts have indeed resulted in a coalition of ongoing support for watershed education through outdoor learning and student-driven action across the region.

The Maryland State Department of Education mandated high school environmental literacy requirement accompanied a newly established set of Maryland State Environmental Literacy standards; one of which required students to investigate a local environmental issue for which they then develop and implement an environmental action plan. Additionally, according to the regulation, every local public school system would be required to provide a *'comprehensive, multi-disciplinary environmental education program infused with current curricular offerings'* that aligns with and supports those standards. (<http://mdrules.elaws.us/comar/13a.04.17.01>). The fundamental purpose of the graduation requirement and Maryland's supporting Environmental Education Program is to *'advance students' knowledge, confidence, skills, and motivation to make decisions and take actions that create and maintain an optimal relationship between themselves and the*

environment, and preserve and protect the unique natural resources of Maryland, particularly those of the Chesapeake Bay and its watershed (<http://mdrules.elaws.us/comar/13a.04.17.0>). The regulation further stipulated that this program should also provide for the diversity of student needs, abilities, and interests at the elementary, middle, and high school learning years, and should include all of the MD Environmental Literacy Standards as set forth in the regulation (COMAR 13A.04.17.01; (COMAR, 2018) (Table 1). Furthermore, each local school system in Maryland was encouraged to establish a support system to enable teachers and administrators to engage in high-quality professional development in content knowledge, instructional materials, and methodology related to environmental education. In terms of student participation, it was expected that all students would have the opportunity to participate in the comprehensive environmental education program required by this regulation to meet their graduation requirement in environmental literacy. Each county school board was able to tailor the curriculum to local community interests, while maintaining core requirements.

Table 1

Maryland environmental literacy requirement has eight key areas.

(1) Environmental issues that would allow students to:
(a) Investigate and analyze environmental issues ranging from local to global perspectives and;
(b) Develop and implement a local action project that protects, sustains, or enhances the natural environment
(2) Interactions of earth's systems that would allow students to analyze and apply the properties of systems thinking and modeling to the study of earth's systems;
(3) Flow of matter and energy which allows students to analyze and explain various aspects of:
(a) The movement of matter and energy through interactions of each of the following earth systems; and,
(b) The influence of matter and energy movement on weather patterns, climatic zones, and the distribution of life;
(4) Populations, communities, and ecosystems in which the student would use physical, chemical, biological, and ecological concepts to analyze and explain the interdependence of humans and organisms in populations, communities, and ecosystems;
(5) Humans and natural Resources in which the students use concepts from chemistry, physics, biology, and ecology to analyze and interpret both positive and negative impacts of human activities on earth's natural systems and resources;
(6) Environment and health, in which the students use concepts from science, social studies and health to analyze and interpret both positive and negative impacts of natural events and human activities on human health;
(7) Environment and society, in which the student analyze how the interactions of heredity, experience, learning and culture influence social decisions and social change;
(8) Sustainability, in which the students:
(a) learn about making decisions that demonstrate understanding of natural communities and the ecological, economic, political, and social systems of human communities; and
(b) examine how their personal and collective actions affect the sustainability of these interrelated systems.

Students entering high school in 2011–2012, were the first cohort of students required to complete a locally-designed high school program to meet the 8 Environmental Literacy Standards (Table 1) approved by the State Superintendent of Schools. These Maryland standards were designed to coincide with, and support, the implementation of existing education initiatives including Science Technology, Engineering and Math (STEM), Next Generation Science Standards (NGSS), Geography Standards, and Common Core Curriculum (MAEOE, 2018). Furthermore, the standards provided a potential model for the implementation of Common Core State Standards and Next Generation Science Standards (NGSS). For example, the first standard calls for students to plan and conduct investigations into local environmental issues for which they subsequently plan and implement a stewardship-driven action plan, thus allowing students to engage in several of the Science and Engineering Practices of NGSS as they make sense of Disciplinary Core Ideas and apply Crosscutting Concepts (NRC, 2012).

Given that these standards challenged school systems to reach beyond functional literacy and skills proficiency, to include critical thinking, analysis, and synthesis of information, consequently, students would be expected to engage in more problem solving and strengthen analytical skills to prepare them for college and careers. Therefore, it was felt that increasing educator capacity to situate academic learning within locally-relevant environmental contexts would allow students to achieve these proficiencies through real-world inquiry. Many school systems identified Standard One (Environmental Issues: Investigate and analyze an issue, and develop and implement a local action project; Table 1) as the most challenging of the environmental standards to achieve at the high school level. They recognized the importance of partnering

with experts in the field to develop authentic and relevant resources and educational experiences that would help schools to meet this environmental literacy standard in a way that addresses these environmental issues with an appropriate civic action in response. Therefore, several collaborating partnerships were established, with the aim of helping school districts accomplish the specific goal for the educational standard for investigating and environmental issue and a follow up civic action activity. One of the partnerships was the Maryland Environmental Literacy Partnership (MELP), which was partially funded by the NOAA Bay Watershed Education and Training (BWET) Program; both of these programs will be highlighted.

These environmental literacy initiatives were further bolstered with the signing of the Chesapeake Bay Agreement Goals of 2014, which was an agreement signed onto by representatives of the governmental leadership of the entire watershed of the Chesapeake Bay, for the first time ever. This included the governors of 6 states (Maryland, Delaware, Pennsylvania, New York, Virginia, West Virginia), the District of Columbia, the Chesapeake Bay Commission and the US Environmental Protection Agency (EPA) signed on to this commitment (CBP, 2014). There were 10 goals in this agreement, which included the Chesapeake Clean Water Blueprint and also established goals for conservation and habitat restoration, improving fisheries, public access to the waterways and also, specifically, environmental literacy. The stated environmental literacy goal was to “Enable students in the region to graduate with the knowledge and skills to act responsibly to protect and restore their local watershed. Make informed decisions concerning the environment; be willing to act on these decisions to improve the wellbeing of other individuals, societies and the global environment and participate in civic life”. In stating this explicitly, they were hoping to reflect both national and international trends in environmental literacy that highlight the topics of sustainability; resiliency of green infrastructure, and human health and well being, which views the Earth as an ecosystem (MAEOE, 2018). Further commitment in 2017 again came with the signing of an Executive Order by the Governor of Maryland establishing “Project Green Classrooms” to ensure every student in Maryland has the opportunity to “experience, understand and learn to conserve the natural environment”. This initiative created an even broader coalition of state agencies and other partners to “mobilize resource and promote outdoor activities and environmental education through schools in communities, and on public lands to benefit Maryland’s young people”. The goal of the expanded group leading this initiative was to build greater capacity to work more effectively across state government, as well as public and private sector partners (MD DNR, 2018).

2.5. NOAA Chesapeake Bay Watershed Education and Training Program (B-WET)

An important driver for the environmental literacy programming in the region and a public source of funding for the MELP project was The NOAA Chesapeake Bay Watershed Education and Training Program (NOAA B-WET). NOAA B-WET was created by Congress in 2002 to help provide hands-on watershed education to students and teachers to foster stewardship of the Chesapeake Bay. This was based on NOAA’s recognition that, *environmentally literate citizens who have the skills and knowledge to make well-informed environmental choices are key to sustaining the nation’s ocean and coastal environments.* (NOAA B-WET, 2018). Chesapeake B-WET funds locally relevant, authentic experiential learning for K-12 audiences through ‘Meaningful Watershed Educational Experiences’ (MWEEs). “Learning is influenced in fundamental ways by the context in which it takes place. A community-centered approach requires the development of norms for the classroom and

school, as well as connections to the outside world, that support core learning values" (NRC, 2012; NOAA B-WET, 2018). MWEES involve learning both outdoors and in the classroom as students engage in issue definition, outdoor field experiences, synthesis and conclusions, and then propose and carry out stewardship and civic action projects. The goal of this program is to increase understanding and stewardship of the Chesapeake Bay and its local watersheds, including the rivers, upland streams, and natural habitats found throughout the region. MWEES have been adopted by the Chesapeake Bay Program in support of the 2014 Watershed Agreement goals as well (see below). Issues-based investigation, which has been conceptualized in the Environmental Literacy Model (ELM) (see below), forms the cornerstone of the program.

MWEES constitute a project-based education approach that allows students to systematically study and evaluate complex environmental issues. By using this MWEES approach, teachers can promote increased student achievement through interdisciplinary, hands-on, student centered projects and involve students in the authentic and situated investigation of issues and problems through a variety of on-campus and community or regional watershed location experiences. In addition, this type of instruction allows students to be engaged in identifying and implementing stewardship and civic action projects that result in a change to the environment (NOAA B-WET, 2018). Various local education agencies and state departments of education have been playing critical roles in supporting, developing and implementing in-school environmental literacy programs. In addition to the NOAA Chesapeake Bay Office and NOAA B-WET programs, the EPA's Chesapeake Bay Program's Education Workgroup connects natural resource agencies, nongovernmental organizations, businesses, colleges, and scientific and professional experts to help education agencies develop and deliver programs that impact environmental instruction in the classroom and the field. A concerted effort toward environmental literacy and education will form the foundation of the goal of an "informed and active citizenry" that can understand and respond to complex environmental problems, which is a goal of the 2014 Chesapeake Bay Watershed Agreement. Funding opportunities and support have been made available through agencies like NOAA and Chesapeake Bay Trust. District of Columbia and partners in Maryland have taken advantage of these opportunities to further environmental education goals.

The B-WET program started in the Chesapeake Bay region, but has expanded nationally with regional programs in Hawai'i, New England, California, the Pacific Northwest, the Great Lakes, and the Gulf of Mexico. In the Chesapeake, B-WET supports the Chesapeake Bay Agreement among States, non-governmental organizations (NGOs) and federal agencies that guide the work of the Chesapeake Bay Program in establishing goals, outcomes, and management strategies for the restoration of the Bay, its tributaries and the lands around them. The "Engaged Communities" goal of the 2014 Chesapeake Bay Watershed agreement formally recognizes the critical role education plays in supporting informed decision-making and stewardship through the Environmental Literacy stated goal to: "Enable students in the region to graduate with the knowledge and skills to act responsibly to protect and restore their local watershed" (CBP, 2014). Along with the above stated over-arching goal, there are three intended "Outcomes" that the Agreement hopes to achieve: The first is *The Student Outcome* which encourages schools to provide students with opportunity for a least one meaningful outdoor experience for each student in elementary, middle and high school. The second is *The Sustainable Schools Outcome* which is an increase in the number of schools in the watershed that are taking steps to actively reduce their impact on the local watershed and the Bay. The third is *The Environmental Literacy Planning Outcome* which encourages local education agencies to develop a long-term plan that guides their student's environmental learning (CBP, 2014, 2019).

2.6. Maryland Environmental Literacy Partnership (MELP)

In 2012, The Maryland Environmental Literacy Partnership (MELP) was created. MELP was a statewide collaboration with the goal of designing and implementing environmental literacy curricula in each of the partnering districts that will meet the state high school graduation requirement by instituting robust issues investigations and student action projects in core science and social studies courses. MELP brought together (a) research scientists from the University of Maryland Center for Environmental Science (UMCES), (b) long standing environmental education providers from the non-profit sector at the Chesapeake Bay Foundation (CBF), (c) the NOAA's Chesapeake Bay Office (CBO), which had been leading efforts in the Chesapeake Bay region to develop and implement strategies for environmental education for decades, (d) Measurement Incorporated, and independent education evaluation group, who implemented and reported on all the evaluative instruments and (e) nine Maryland school districts. All the participants in this partnership were tasked to help develop Environmental Education curriculum for general science and social studies programs (as opposed to exclusively for environment/ecology courses), in order to meet the new state education department requirements. A very specific aim was to train both science and social studies teachers in environmental education topics, and to deliver a professional development package for high school teachers providing content knowledge and skills to meet Maryland's environmental literacy requirement, (i.e., Standard One). Additionally, quality environmental issues investigations also played a dual role of providing a potential model for the implementation of Common Core State Standards and Next Generation Science Standards (NGSS) (NAS, 2012). Given that these standards challenged school systems to reach beyond functional literacy and skills proficiency to include critical thinking, analysis, and synthesis of information, students would be expected to engage in more problem solving and strengthen analytical skills to prepare them for college and careers. Therefore, it was felt that increasing educator capacity to use locally-relevant environmental issues as a context for learning would allow students to achieve these proficiencies through real world inquiry.

To help with these endeavors, one of the key activities MELP conducted were professional development programs, called "summer institutes" from 2012–2017 (Fig. 6). During the week-long immersive programs, teachers spent an intensive period in the field, with approximately 15–20 other teachers, and the MELP team. Similar to the NY professional development programs, the teachers received stipends and/or graduate credits. The content emphasized Chesapeake Bay and watershed science and related it to geographical literacy issues. During these weeks, teachers participated in field programs on Chesapeake Bay Foundation vessels and overnights at Chesapeake Bay Foundation field stations, modeling an "environmental issue investigation" topic. The environmental issue for the summer institutes focused on comparing land use and water quality along an eutrophication gradient; first in Baltimore Harbor, and then in a rural area of Chesapeake Bay off of Smith Island (Fig. 5). With the MELP team acting as the instructors and the teachers as the "students" for the week, the educators learned how to implement and incorporate environmental literacy into the teachers' respective different areas of teaching, providing the opportunity for teachers from each school district to develop a solid understanding of the field-based pedagogy, and content, including not only science, but social studies, and in some cases, art, as well.

Participating teachers, with the help of the MELP team and mentor teachers, applied the knowledge and skills gained during summer institutes to the development of specific environmental issues investigations for their target courses in their school



Fig. 6. (A) Teacher Environmental Literacy Model (ELM) planning workbook: *Chesapeake Classrooms Teacher's Guide*. Chesapeake Bay Foundation, Annapolis, MD; Summer Institute field trips for teacher training in ELM model and investigative issues implementation in (B) Baltimore Harbor, and (C) and (D) Smith Island in the Chesapeake Bay.

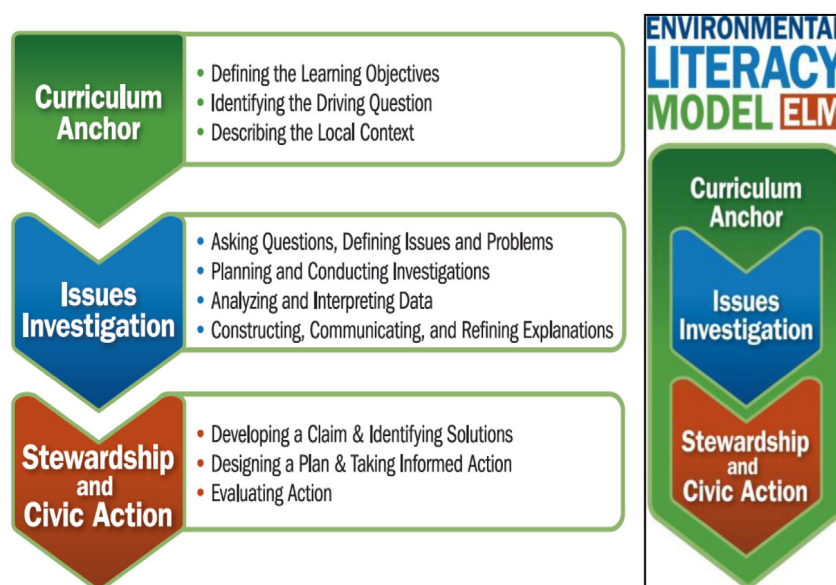


Fig. 7. The Maryland Environmental Literacy Model (ELM) sits within a Curriculum Anchor in which “Issues Investigations” and “Stewardship and Civic Action” are embedded (MELP 2016).

community. This was incorporated into a culminating project assignments, where each teacher developed and submitted a ‘Curriculum Integration Project’ based on the frameworks introduced during the training. The teachers received feedback on their project plans and made differentiated revisions to their selected education modules during the school year. A peer training model for teacher-to-teacher professional development was also implemented where teachers who participated in a “summer institute” could then be selected to act as mentor teachers for subsequent summer institutes and throughout the school year in their districts. This created a cadre of teams of science and social studies Mentor Teachers who created follow-up workshops, module implementation with field investigations, and mentoring workshops. Ultimately, the Mentor Teachers were then equipped to help instruct as Peer Teachers within their schools in a “train the trainer” model, insuring continuity and sustainability beyond the scope of this program. The ultimate goal of MELP was to have an adoption-ready, extensively piloted curriculum module

in science and social studies prepared for each partner school. The NOAA B-WET Program provided MELP with funding to extend its reach to additional school districts. In the last year of the summer teacher programs in 2017, the program was modified to integrate vertical articulation (middle school to high school) progression, and also to include some elementary school teachers.

The MELP partners incorporated the investigative framework into the Chesapeake Bay Foundation’s “Chesapeake Classrooms Teacher’s Guide” (Fig. 6A; CBF, 2018), and the investigative framework solidified with the creation of the Environmental Literacy Model (ELM) (see below; Fig. 7) which was further refined by NOAA CBO and EPA CBP. (Sprague et al., 2019). Teaching modules, developed by MELP, were also modified to meld scientific and social issues in a geospatial context, which addressed Chesapeake Bay and its watershed and focussed on action projects to provide students with a meaningful watershed educational experience (MWEE), incorporating a goal of the NOAA B-WET

Program. Additionally, *The Chesapeake Bay Program* helped Maryland and other states in the watershed meet the environmental literacy goals of the Chesapeake Bay Watershed Agreement. CBP partners have committed to building on the success of MELP to further develop standardized frameworks (ELM) for developing systemic MWEEs that meet the state's environmental literacy standards (as well as other disciplinary standards) and helps school districts ensure all students meet the environmental literacy graduation requirement (Table 1). They have also developed an Educator's Guide, accompanying tools, and an online training system for high-quality professional learning in support of these goals expanded and refined the ELM Model (Fig. 7), which had its beginnings as part of MELP, and is an environmental literacy model is transferrable to any system (Sprague et al., 2019).

2.7. The Environmental Literacy Model (ELM)

The Environmental Literacy Model (ELM) (Fig. 7) was developed from the environmental issues investigations framework, through the Maryland Environmental Literacy Partnership and has since been updated by leaders within the Chesapeake Bay Program Education Workgroup for use with B-WET Program MWEEs (CBF, 2018; NOAA, 2018), building on the success of MELP to develop standardized frameworks (ELM) for developing systemic MWEEs that meet the state's environmental literacy standards (as well as other disciplinary standards) and help districts ensure all students meet the environmental literacy graduation requirement.

ELM has three main components to help structure environmental modules: (1) a Curriculum Anchor; (2) an Issues Investigation, and (3) Stewardship and Student Civic Action (Fig. 7). These three components provide a framework for integrating the environmental issues investigations and civic engagement into embedded academic curricular programs. The ELM approach to curriculum integration is useful at multiple scales (i.e., from curriculum writers and coordinators at district and state levels; to grade-level school teams; to the individual classroom teachers), in facilitating curriculum integration, while simultaneously supporting pedagogical understandings of how student achievement may be enhanced through environmental literacy (Sprague et al., 2019). The framework for the ELM was first outlined in workbook *Chesapeake Classrooms: Teacher's Guide* prepared by MELP partners from the Chesapeake Bay Foundation's Education team (CBF, 2016) (Fig. 6A). This guide book helps teachers to organize the planning process for field-based-inquiry in a very straight forward way. It is available online, and is updated with improvements each year. This has been updated and modified by the Chesapeake Bay Program Education working group in 2017. The updated Educator's Guide and 'Planning Toolbox' is augmented by a very useful online resource called "BayBackPack" An Educator's Guide to the Meaningful Watershed Education Experience and the MWEE Toolbox developed by the Chesapeake Bay Program, NOAA, Chesapeake Bay Foundation, and the Chesapeake Bay Trust for teacher resources on how to use the ELM model to help design a MWEEs (Sprague et al., 2019).

In the first component of the model (Fig. 7), the teacher defines the learning objectives within the *Curriculum Anchor* and the performance expectations. Engaging students' interests on particular topics can help establish the local context and how a given topic is relevant to the local community, to come up with a "driving question". The second component is the *Issue Investigation* component, where students define the issue, problem or phenomenon to be investigated and develop questions that will address the matter. The students, with teacher guidance, then develop plans for collecting, analyzing, and communicating information and/or data in a collaborative manner, to help them

answer their questions and understand the problem (Sprague et al., 2019). Field trips or excursions can then be planned around collecting the required data and information regarding the issue they are investigating. This data and information is then analyzed back in the classroom where students can synthesize data and discuss results for a refined conclusion.

The third component of the ELM is *Stewardship and Civic Action*. In this portion, the students take the information that have gathered about their driving question, and develop a claim, or position, based on the facts of their analysis. This provides an opportunity for students to adapt what they have learned during the Issues Investigation and apply it to meaningful action to help resolve the environmental issue being investigated. The students work in small teams to develop their statements of position and make claims based on their conclusions. Students implement their plans, and then follow up with a reflection on the success of the action activity and whether their action plan successfully addressed the problem and whether their initial claim may need to be modified, as well as what information they can share for sustaining or extending the action for future students (Sprague et al., 2019). This third component is the part of the model that is likely the most aspirational, as teachers indicated during the evaluation process that this is the piece that realistically is the hardest to implement given time and resources.

2.8. Maryland Environmental Literacy Partnership Summer Institute Outcomes

Overall, the MELP program professional training was very well received by the teacher participants. Between 2013 and 2016, 150 middle school and high-school teachers participated in the Summer Institutes and the professional learning programs. Evaluation surveys were conducted each year of the project and overall the teachers who responded were satisfied with their professional development experience ($n = 53$). They reported significant gains in their understanding about how their environmental educational modules could meet existing standards and/or fit into the curriculum and how their district-wide professional learning communities could help support piloting an environmental literacy module in their classrooms. Furthermore, nearly all (95%) of responding teachers indicated that this approach would enhance student abilities in understanding subject content (Goodwin-Segal, 2016). Over one-third of participating teachers implemented the environmental literacy module in their classrooms up to the point of the student action/civic engagement component and then postponed that work until later in the academic year. The student action projects were implemented by slightly less than one-half of the teachers. Completing this final element of the framework seems to be the most difficult in terms of resources and time for the teachers, and this is an area that could be improved upon in the future. 100% of piloting teachers indicated that they felt that the environmental literacy modules did indeed address the Environmental Literacy Standards; the Next Generation Science Standards (NGSS); and also met the criteria for a MWEE to a moderate/great extent.

In terms of student benefits, teachers indicated that students when using the constructed environmental literacy modules, were actively engaged in learning, and that their content knowledge improved. Nearly all (>95%) of the responding piloting teachers agreed or strongly agreed that students were (a) better able to identify and relate to environmental issues facing Maryland, (b) better able to relate learning to real world applications, and (c) improved their ability to construct explanations about an environmental issue (Goodwin-Segal, 2016). Other key student outcomes from implementation of environmental literacy modules included that >92% of teachers ($n = 41$) reported the

following: (a) students were better able to relate learning to real world applications, (b) students improved their ability to work collaboratively to address environmental issues, and (c) students were actively engaged in the material.

Challenges that were reported by teachers completing the implementation surveys ($n = 17$), most frequently cited time constraints (77%), competing priorities (57%), planning time (30%), and lack of applicable resources as challenges to classroom implementation. Planning time to incorporate a project-based, inquiry approach can be difficult unless supported by the teachers' department/ administration. Consequently, for these environmental modules to be adopted as a part of the curriculum, there needs to be strong administrative support and a plan for offering teachers professional development that is high-quality and ongoing. Integrating environmental literacy modules with other initiatives (e.g., Common Core, Next Generation Science Standards, STEM-C, etc.) requires leadership and a well-designed, well-executed implementation plan.

Teachers and district-level facilitators/administrators helping teachers implement these standards felt (a) that the instructional methods are now more aligned and integrated with environmental literacy standards; (b) that teachers are more aware of environmental literacy standards; (c) that teachers are implementing *Issues Investigations* and *Civic Engagement* methods with students and (d) that more learning resources are available/accessible in the district that could help teachers. Of the responding teacher participants, in 2016, more than 90% agreed or strongly agreed that the program provided content and strategies that will be useful in their teaching. Furthermore, 86% agreed or strongly agreed that there were good ideas/discussions about using the ELM *Issues Investigations* and *Civic Engagement* approach in high school science and social studies courses. Based on the teacher participant perceptions, there was a significant increase in their knowledge about environmental issues as a result of participation in the Summer Institute. At the end of the Summer Institutes, teacher participants reported a significant increase in their ability to use targeted pedagogical methods such as field-based experiences and inquiry methods to teach environmental education.

Participants were highly satisfied with the summer professional development program and indicated that the program was well organized; and motivated them to integrate environmental literacy programming using the MWEE in their classroom teaching. There were significant gains in participating teachers' knowledge about environmental issues, Maryland requirements, and the Chesapeake Bay and Watershed Agreement (CBP, 2014) including the MWEE requirement stated in the Agreement's Environmental Literacy Goal. Participants reported significant gains in their ability to use targeted pedagogical methods and to implement components of MWEEs. Participants indicated that students will benefit from implementing comprehensive environmental literacy instruction/MWEEs in a number of ways. The highest levels of agreement were that students will improve their ability to: 1. know positive and negative environmental impacts and identify the issues facing Maryland, 2. formulate hypothesis and take a stand on an environmental issue; 3. work collaboratively to address an environmental issue, and 4. demonstrate a sense of civic responsibility to protect the environment (Goodwin-Segal, 2017).

2.9. Future directions

Designing Environmental Literacy Plans (ELPs), which are comprehensive frameworks that support school systems in expanding and supporting environmental education programs is complicated (NAAEE, 2014). Despite the immense need of integrating environmental education into schools across the United States,

this has proved challenging and different states have taken different approaches in the development and implementation of these plans. Maryland's ELP plan was highlighted, along with a handful of other states, in a report by NAAEE (2014) as having an 'exceptional plan'. The report noted the unique attributes of several states' 'outstanding plans'. Maryland stood out for having created a "well-informed plan", based on extensive research, with a wealth of baseline data collection to build on (NAAEE, 2014). In addition to the very strong state government support, the Maryland plan was commended for reaching out to underserved communities, and tailoring the plans to fit Maryland's unique needs and to prioritize the concerns of its citizens. They also noted that a strong foundation on solid research, makes implementation and integration more possible, and having baseline data, allows for development of metrics for success (NAAEE, 2014). Maryland's efforts at establishing these environmental literacy standards received international recognition as well, receiving an award from the World Future Council, the Inter-Parliamentary Union, and UNICEF. In particular, the state was recognized for being the first in the nation to require students to be environmentally literate as a high school graduation requirement. Other states, such as Kentucky and Utah have since developed education plans based on Maryland's Environmental Literacy Standards. They noted at the time of the award that "early results look positive with sustained school-wide changes in knowledge, behavior, and action and broad improvements in student's learning outcomes across a wide range of subjects" (WFC, 2015).

Many of the education programs are now shifting to directing and supporting systemic implementation of environmental literacy programming at the school district level, including student MWEEs and sustainable schools efforts. It involves embedding environmental issues and outdoor learning into the K-12 curriculum for entire cohorts of students and adopting supportive operating practices at schools to ensure that every student has equitable access to this powerful approach to teaching and learning. It requires school districts to ensure that teachers receive high quality professional development to provide them with the content knowledge and pedagogical skills for using the outdoors as a context and approach for learning. Much of the guidance now rests with the state Departments of Education, school districts and schools. The Chesapeake Bay Program Education workgroup and partnership is continuing to work with education partners in the region to achieve the Environmental Literacy goal, enabling every student in the region to graduate with the knowledge and skills to act responsibly to protect and restore their local watershed (CBP, 2019).

3. Summary

We have described two successful regional environmental literacy programs with deep cultural roots and value ascribed to their associated waterways including large, modern harbors. In most operational details, the two programs were different. The New York program concentrated specifically on oysters and water quality in the urban setting, while the Maryland program explored land use and human impact issues by comparing conditions in an urban and rural area, which was used as an 'environmental issues investigative' model. However, both programs required broad collaborations between education officials, school administrators, funding agencies, environmental and regulatory agencies, and scientists. Within the science community, both regional efforts required reaching across disciplinary specialties, and combining earth and environmental science with biology, ecology, physics, chemistry, geography, and in some cases the arts. At the center of both programs were in-service classroom

teachers and professional development opportunities. In addition to learning new subject-matter content, student success hinged on these professionals expanding their capacity for outdoor education, for active, experiential learning formats, and for issue-oriented, student-empowering pedagogy. Involving experts in the field, from across disciplines, served to provide teachers and their students with the critical authentic contextual references and multiple representations of context required for deep learning (Driscoll, 1994; Knobloch, 2003). Thus, we conclude that these two aspects (broad, inclusive collaborations and centering in-service teachers) are essential to successful large-scale environmental literacy projects in coastal and urban settings.

The evolution of the two programs is also indicative of the time-scales required for successful environmental literacy programming. To develop curricular concepts and produce associated materials, recruit teachers and other citizen science volunteers, and implement professional development structures, these initial tasks constitute several years of work. For the effort to extend beyond teachers into schools and neighborhoods – to see results among children and teens, where it is most needed – takes some years beyond project development. In round numbers, we conclude that environmental literacy impacts need to be measured in decades, rather than years. Such time scales will require a paradigm shift in how resources, including development funding, are allocated.

Large scale partnerships provide the opportunity for educational models to work in conjunction and create opportunities for students to explore their environments, take ownership of their communities, gain critical problem-solving skills and participate in environmental restoration field science research. The two education initiatives described here in New York and the Chesapeake vary in scale and approach but share the similar goals of engaging students and citizens in authentic, place-based science that is of relevance to their surrounding communities. Many harbor cities around the globe share similar environmental issues, and restoration initiatives and both the CCRES and MELP/B-WET models could serve as the foundations for other regions and cities to implement environmental literacy programs. Environmental issues are occurring at a global scale, therefore educating environmentally-literate citizens is a global issue and a global imperative.

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