JSO JOURNAL of STEM OUTREACH

Vol. 4, Issue 1, September 2021

Food, Energy and Water Learning Module Workbooks (FEWLM): Low-Cost Affordable Inquiry-Based STEM Curricula

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Keywords: Scientific process, data analysis, STEM outreach, elementary and middle school youth, FEWLM workbooks, systems learning

Publication Date: September 22, 2021

DOI: https://doi.org/10.15695/jstem/v4i1.10

ABSTRACT: The Diverse and Integrative STEM Continua Using Socio-environmental Systems In and Out of Neighborhoods (DISCUSSION) network core team developed a low-cost, interdisciplinary, inquiry-based STEM curriculum of workbooks called the Food, Energy, and Water Learning Module (FEWLM). Built on the Next Generation Science Standards with a systems thinking approach, these workbooks provide hands-on, self-driven and team-building activities for elementary and middle school youth with the intent to increase their scientific exposure and awareness about environmental sustainability and human health issues. FEWLM was implemented at local Boys and Girls Clubs, local public after-school programs, and the DISCUSSION "HydroPHonics" Summer Enrichment camp. More than 150 underrepresented minority youths were engaged in our FEWLM science learning events during a two-year period; however, approximately 50 youths were surveyed about their experiences with FEWLM, attitudes and interest in science, and career ambitions. Evidence indicated that our FEWLM learning experiences had a positive impact on elementary and middle school youth by increasing their interest in STEM, perception of STEM in their lives, and confidence in their ability to participate in STEM.

INTRODUCTION

A diverse, skilled, and innovative Science, Technology, Engineering and Mathematics (STEM) workforce is critical for the nation's well-being, economic competitiveness, global leadership, security (National Academy of Sciences et al., 2011; President's Council of Advisors on Science and Technology (U.S.), 2012) and development of sustainable communities (Goudie, 2009). For decades, African Americans/Blacks, Hispanics/Latinos, American Indians, Alaskan Natives, and Native Hawaiians, and Pacific Islanders have been underrepresented minorities (URM) in STEM fields (National Center for Science and Engineering Statistics, 2019). Although the percentage of URMs receiving undergraduate and graduate degrees in STEM is slowly increasing, the proportion of URMs attaining STEM degrees and employment in the STEM workforce, especially in mathematics, statistics and physical sciences, is consistently low (National Center for Science and Engineering Statistics, 2019). Long-standing social and economic barriers in our society have contributed to the underrepresentation of minorities in STEM fields and careers (de Graaf et al., 2005; Musters et al., 1998), and path diversions are exhibited as early as the K-12 levels, (National Center for Science and Engineering Statistics, 2019). The complex interacting socio-economic factors affecting marginalized communities burdens students with poverty, under-resourced public education, underachievement, loss or lack of interest in STEM, under-preparedness for college, and family obligations, thereby severely limiting the number that can pursue STEM degrees thus preventing potential increases in the number of minorities as STEM professionals (President's Council of Advisors on Science and Technology [U.S.], 2012).

Across the United States, a large percentage of minority youth are disadvantaged because their lives are constrained by one or more socio-economic barriers, such as, single-parent households, parents with low educational levels, unemployed parent(s), frequent residential changes or homelessness, food insecurity, household poverty and impoverished community, and attending low-performing public schools. These are risk factors that have been linked to poor academic performance of students (Robbins et al., 2012). Often un-

derrepresented minority (URM) youth from these "at risk" backgrounds lack opportunities to participate in STEM experiences early in their education, and consequently many do not perceive STEM as relevant to their lives. URM youth lacking an early and positive connection to STEM reach middle school already having developed a negative perspective of science and nature (Goodwin, 2016), and their motivation to learn this subject is diminished (Dweck, 2007). Evidence suggests that URM youth become more motivated and gain more interest in STEM when they are exposed to culturally-relevant science learning experiences that emphasize direct connections of STEM to their culture and community (Estrada et al., 2016). Furthermore, encouraging these youths to adopt "growth mindsets" increases their motivation to learn and helps them develop the skills to tackle challenging problems, foster coping strategies to overcome setbacks, and combat negative stereotypes (Dweck, 2007).

Increasing environmental, economic and political pressures stemming from population growth, climate instability, heterogeneous distribution of natural resources, habitat destruction and land use cause imbalances in the natural systems that provide our food, energy, and water (FEW) (Mohtar and Daher, 2012). It is imperative that our society develop an informed citizenry so we can devise the best approaches to integrate natural and human-built environments to support a growing demand for FEW (Mohtar and Daher, 2012), while conservatively and efficiently managing irreplaceable natural resources such as freshwater, fertile soils for agricultural crop and medicinal vegetation generation, and regulation of climate change (Daily et al., 1997). Developing a populace that is STEM-literate begins with educating our youth. Innovative, student-centered, evidence-based curricula that engage youth early and sustain their interest in STEM should contribute also to broadening the participation of URM students in STEM (President's Council of Advisors on Science and Technology (U.S.), 2012). Moreover, the Vision and Change Report recommends creating inquiry-based learning modules for formal and informal STEM educational settings that stimulates curiosity for STEM (AAAS, 2011) and develops an appreciation of nature, as interrelated ecological processes instead of fragmented scientific facts (Goodwin, 2016).

Providing a curriculum that actively engages youth to build core competencies in the practice of science, including hypothesis testing and data interpretation in addition to self-reflecting on their learning experience, enhances STEM learning (AAAS, 2011; Goodwin, 2016). This has been shown especially to be the case for elementary school youth from diverse demographic groups, classified by socio-economic status, gender, achievement level, and English proficiency levels (Cuevas et al., 2005). For instance, Cuevas et al. (2005) find that employing an inquiry-based intervention significantly improves the ability for elementary school youth to conduct scientific inquiry and more specifically implement procedures, record information, and make conclusions. While Marx et al. (2004) affirms that an inquiry-based and technology infused curriculum can help middle school students who are in underperforming urban schools to learn science, several other studies also provide strong evidence of the positive impacts of using an inquiry-based curriculum to improve academic achievement at the elementary and middle grade levels (Abdi, 2014; Şimşek and Kabapınar, 2010). However, studies have shown major challenges associated with dissemination and implementation of empirically proven curriculum (Estrada et al., 2011; Harper and Griffin, 2011) designed to narrow the achievement gap and increase STEM literacy for minority children at the elementary and middle school levels (Lent et al., 2005; National Academy of Sciences et al., 2011).

Our project attempts to improve access to high-quality STEM learning experiences for URM students in K-12 grades who traditionally have been underserved. Our work is part of a national effort supported with funding from the National Science Foundation's Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science (NSF INCLUDES). NSF INCLUDES is a comprehensive national initiative designed to enhance U.S. leadership in STEM discoveries and innovations by focusing on broadening participation in these fields at the national scale. Entitled, "The Diverse and Integrative STEM Continua Using Socio-environmental Systems In and Out of Neighborhoods (DISCUSSION)", our project is an educational alliance, led by two historically black universities, North Carolina A&T State University (NCAT) and North Carolina Central University (NCCU). The purpose of DISCUSSION is to build and sustain partnerships that develop and promote socio-environmental resilience. The DISCUSSION core team envisioned achieving this goal by increasing the number of prepared, motivated underrepresented students attaining careers by disseminating evidence-based interventions as low-cost inquiry-based science learning materials that emphasize scientific literacy, knowledge retention, and quantitative skills. The DISCUSSION core team partnered with a community college, a public school system, and several community non-profit and faith-based organizations to create a DISCUSSION network.

The DISCUSSION network takes a socio-environmental system approach to promote a common view of natural resources for sustaining communities. We present an integrative approach for teaching science while informing youth about the connection between the environment and human health, through a student-centered, inquiry-based curriculum focusing on the food, energy and water (FEW) nexus (Mohtar and Daher, 2012). Therefore, the DISCUSSION core team identified, developed, and implemented a FEW Learning Module (FEWLM), which is a scaffolded, low-

cost, inquiry-based learning curriculum built on the Next Generation Science Standards (NGSS) (National Research Council, 2013; NGSS Lead States, 2013) designed for formal educational programs, after school programs, summer camps, homeschool instructors and other STEM outreach programs (Table 1). Through the development and dissemination of an engaging inquiry-based curriculum which emphasizes the scientific process, quantitative literacy skills and environmental sustainability focused on the FEW nexus, our DISCUSSION Network will contribute to broadening participation in STEM. These fun, integrative, system-thinking, system-modeling STEM activities intervene at the elementary and middle school critical juncture to engage "at risk" underrepresented and underserved youth in scientific inquiry-based learning while providing a culturally relevant learning experience and encouraging them to become interested in STEM careers. Here we describe: 1) development and implementation of the FEWLM curricula, 2) student perspectives about FEWLM, and 3) successes, challenges and limitations as a resource for educators to implement in their formal and informal educational programs.

METHODS

Curriculum. The idea of affordable programming was the guiding principle in identifying, designing, and developing FEWLM. It was conceptualized by the DISCUSSION Network core team to address the issue of access through lowering socio-economic barriers that limit participation in STEM for minority communities. FEWLM is an assembly of age-appropriate, culturally-sensitive STEM curricula workbooks infused with an environmental conservation, sustainability, and human health foci. The curricula development started with evidenced-based science learning materials that we modified to be hands-on, self-driven and team-building activities and then compiled into workbooks (Ahmed et al., 2021; Carlsen et al., 2010; Khoo et al., 2017; Nolte, 2008; Science Buddies, 2012; Spence et al., 2020). The curricula emphasize the application of scientific inquiry, quantitative literacy, conceptual understanding, and data analysis and interpretation. These FEWLM workbooks were developed by members of the DISCUSSION core team. The content was designed to provide an educational experience for elementary and middle school youth to engage in the scientific process and comprehend science, not as isolated facts, but as collective concepts that interlink ecological systems with human well-being. Through FEWLM, the youth are encouraged to act like scientists by working individually or collaboratively to observe, record, graph, analyze and interpret data to test a hypothesis and formulate a conclusion. Self-reflective, open-end questions are provided to encourage students to think about what they learned while completing the workbook.

This curriculum is a responsive plan that benefits a large number of "at risk" elementary and middle school youth who might otherwise have been disregarded as potential STEM professionals by exposing them to "real world" problem solving using the scientific process. Furthermore, emphasizing problem-solving approaches to environmental issues stimulates interest, motivation, and self-efficacy for STEM learning for students and improves STEM education for teachers (Bandura and Locke, 2003; Musters et al., 1998; Trauth-Nare, 2015). Guided by the NGSS, the set of FEWLM workbooks collectively invoke use of the eight (8) science and engineering practices: Asking questions and defining problems; Developing and using models; Planning and carrying out investigations; Analyzing and interpreting data; Using math and computational thinking; Constructing

Table 1. *FEWLM modeling and real-world applications with Bloom's Taxonomy (Anderson, 2001).*

Module Number	FEWLM Module	Modeling Applications and STEM Features	Real-World Environmental Applications	Bloom's Taxonomy
1	Scientific Inquiry with Decimals and Fractions through the Colorful World of m&m's Workbook OR Exploring Scientific Inquiry and Mathematical Thinking with Skittles Workbook	Math Applications Basic Statistics Sample Replication Data Collection Data Analysis	Scientific Inquiry	Understand Apply
2	My Sprouting Bean Seeds Scientific Workbook	Seed Germination Biological Organisms	Food Insecurity	Understand Apply Analyze
3	Let's Take a Biochemical Journey Through Osmosis with a Naked Hen Egg Workbook	Cell Structure Cell Membrane Osmosis	Health Disparities	Understand Apply Analyze
4	The Beneficial Health Impacts of Fruits and Vegetables	Cell Membrane Biochemistry	Health Antioxidants pH	Understand Apply Analyze
5	Exploring the Link Between Land Management, Plant Growth and Water Quality Using a Mini-Garden Model	Plant Growth Water Quality Land Management	Water Pollution Food Insecurity	Understand Apply Analyze Synthesis

Note: Anderson, L. W., and Krathwohl, David R. (2001). A taxonomy for learning, teaching, and assessing: a revision of Bloom's taxonomy of educational objectives. Longman.

Table 2. *FEWLM workbook, estimated workbook page lengths, instructor prep and activity time, group size and estimated costs.*

FEWLM Workbook	Estimated Workbook Page Length	Instructor Prep Time	Activity Time	Group Size	Estimated Cost
Scientific Inquiry with Decimals and Fractions through the Colorful World of m&m's® Workbook	10 pages	30 min in Advance	**Part I**. 45 to 120 min **Part II**. 60 to 120 min	**Part I.** Individual **Part II.** 5 students	$46 USD $6 USD
Exploring Scientific Inquiry and Mathematical Thinking With Skittles Workbook	10 pages	30 min in Advance	**Part I.** 45 to 120 min **Part II.** 60 to 120 min	**Part I.** Individual **Part II**. 5 students	$46 USD $6 USD
My Sprouting Bean Seed Workbook	27 pages	24 hours in Advance	7 - 10 days	**Part I**. Individual **Part II.** 5 students	$26 USD
Let's Journey Through Osmosis with a Naked Egg Workbook	16 pages	48 hours in Advance	1 hour 3 days	**Part I**. Entire Class **Part II.** 5 students	$53 USD
The Beneficial Health Impacts of Fruits and Vegetables	15 pages	3 hours in Advance	4 hours	**Part I.** 4 Students **Part II**. 4 students	$28 USD
Exploring the Link Between Land Management, Plant Growth and Water Quality Using a Mini-Garden Model	42 pages	24 hours in Advance	Up to 19 days	5 Students	$100 USD

Note: The estimated workbook page length provided in the table does not include the pages for providing instructions, preparation, and background information for instructors.

an explanation and designing a solution; Engaging in an argument stemming from evidence; Obtaining, evaluating, and communicating information. The specific NGSS learning objectives vary based on the scope of the activity and provided with each workbook. The elementary and middle school NGSS learning objectives for each workbook is provided in Table A and Table B in the Appendix, respectively. The "inquiry" framework uses mathematics and systems-thinking processes of science and engineering to prepare K-12 students from diverse socio-economic and ethnic backgrounds to develop an in-depth understanding of content as well as develop key skills such as communication, collaboration, inquiry, problem solving and flexibility that will serve them for college, careers and citizenship (Januszyk et al., 2016).

Most science activities consist of worksheets with pre-determined answers, which is not science. This curriculum provides students with the opportunity to learn, practice, and apply the scientific process while learning the interconnections between food, energy and water. The data collected during these activities are not pre-determined and will vary each time the experiments are conducted. Moreover, the youth will learn, practice and apply skills such as observing, recording, graphing, analyzing and interpret data to test a hypothesis and formulate a conclusion.

The suggested total cost for the complete the activities in the set of FEWLM workbooks is less than $300 for a class size of 30 students (Table 2); the cost decreases with a smaller class size. The cost to implement the individual workbooks varies between $26 and $100. The items needed to conduct the targeted activity can be purchased at the local Dollar Tree, Walmart, Lowes, pet store (e.g., PetSmart) or grocery store for reasonable prices, unlike other companies and organizations that provide science kits. The suggested store and price for each item required to complete a specific FEWLM activity is provided with the instructor's information at the beginning of each individual workbook. The overall cost will decline significantly during subsequent years because several items can be reused. Suggestions for reducing the total FEWLM cost consist of (1) including items on the classroom supply list at the beginning of academic year, (2) asking parents to donate items during the academic year, (3) purchasing school supplies in August during the "back to school" sale or (4) ordering the supplies online and shipping them to the respective store to avoid shipping cost. The time required to complete each workbook varies from 2 hours to 19 days and is dependent on the particular activity (Table 2).

Food Energy and Water Learning Modules. Completing the series of FEWLM workbooks in a sequential order provides a scaffolded learning experience for 3rd – 8th graders. Scaffolding the curriculum allows for the repetition of learning, practicing, and applying the scientific process (D'Costa, 2013), recognizing a connection between the environment and human health and fostering quantitative literacy (Figure 1). Instructors can select specific workbooks that align with their grade level curriculum. These workbooks are designed to be appropriate for 3rd – 8th grade levels. After downloading the FEWLM, worksheets will be printed as loose sheets

Figure 1. Title page for each FEWLM Workbook.

Figure 2. Credit to the graphic designers work used to create FEWLM workbooks.

initially. Worksheets too advanced for a specific grade level can be removed or not printed prior to assembling and stapling the worksheets to create a workbook. Part I consists of individual activities that are primarily designed to engage elementary school youth. Advanced versions, such as Part II of each workbook, are designed to provide the middle school youth with a more independent and collaborative learning experience. Instructions for teachers to effectively implement these activities as well as the elementary and middle school NGSS learning objectives are provided with each workbook. The FEWLM workbooks were designed using graphics available at teacherspayteachers.com (Figure 2). A detailed description of each workbook (Spence et al., 2021) is described below:

Scientific Inquiry with Decimals and Fractions through the Colorful World of m&m's® Workbook. During this two-part activity, elementary and middle school youth learn the scientific process and engage in mathematical thinking while enjoying an edible treat. Moreover, they learn to record, analyze, and interpret data gathered from tallying and sorting plain chocolate m&m's® by color characteristics. Students learn how to use their data to create bar graphs, which is a valuable tool for interpreting and communicating results. The overall goal is to promote mathematical thinking by determining whether the percentage of colors in each bag of m&m's® is identical. Part I, focuses on learning how to tally and sort data into categories followed by rudimentary mathematics such as calculating ratios and percentages, in fraction and decimal form. Part II, a continuation of part I, aims to teach elementary statistics such a calculation of the mean, median, and mode as well as introduction to sample replication and variability. The required time to complete the *Scientific Inquiry with Decimals and Fractions through the Colorful World of m&m's®* workbook is estimated to be 2 hours. Instructors can divide this activity into two one-hour sessions. For example, instructors can divide this activity into one-hour, in-class sessions on two different days or a one-hour, in-class session with students completing the data calculations and open-ended questions as homework (Spence, 2021).

Exploring Scientific Inquiry and Mathematical Thinking with Skittles Workbook. The skittles activity is an exact replica of the m&m's® activity and an excellent alternative for students who are allergic to nuts and chocolate. An estimated time frame of two hours is also required to complete this activity.

My Sprouting Bean Seed Workbook. This two-part inquiry-based activity is an adaptation of the "Pocket Seed Viewer" provided by ask a biologist (https://askabiologist.asu.edu/content/pocket-seed-viewer) that is designed to allow students to practice the scientific process. During this activity, students learn about the seed germination process, the history of black, pinto and lima beans as a staple food for Central, North and South American indigenous cultures, respectively, and the human health and environmental benefits of including beans in their diet (Figure 3). During Part I, the youth observe and compare the root and shoot growth rate of black, pinto and lima beans in a pocket seed viewer over a seven-day period. They also learn how to create a line graph using the average growth length of root and shoot over the seven-day period and how to analyze and interpret the results. During Part II, the middle school youth continue to learn the importance of sample replication and variability via working collaboratively as a team of five "student researchers" by combining their individual data to calculate average, median, and mode for the growth length of root and shoot for each bean. Students use line graphs to illustrate the average growth rate of root and shoot over the seven-day period for each bean. The required time to plan and set up their experiment and record the initial quantitative and qualitative measurements for the *My Sprouting Bean Seed* workbook is 2 hours. The required time to conduct quantitative and qualitative seed germination measurements is 1 hour per day over a 7-day period. On days 8 and 9, instructors will need

Figure 3. Example of FEWLM worksheets for seed germination and mini-garden model workbooks.

1 hour to complete Part I of the experiment. Part II requires 1 hour to calculate the basic statistics, create line graphs, and answer the open-ended questions as homework (Spence, 2021).

Let's Take a Biochemical Journey Through Osmosis with a Naked Hen Egg Workbook. This is a classic hypothesis-driven, inquiry-based experiment that introduces fundamental biological and chemical laws and theories as a result of understanding osmosis and the effects of hypotonic, isotonic, and hypertonic conditions using naked hen eggs as a cell model. This model helps students learn how different types of cell-environment interactions occur in their bodies from common foods most people eat (Figure 3). They discover the negative impacts of unhealthy eating habits on their cellular function and the molecules that lead to human diseases such as diabetes, obesity, and high-blood pressure. These diseases are known to plague the African American communities (United States Department of Health and Human Services, 2021). Moreover, students observe how naked eggs respond in different environments to demonstrate how cells in our bodies act in response to foods that create environments that are high in salt, sugar, etc. During Part I, the youth observe osmosis in the naked egg cell model using various salt concentrations while expanding their knowledge about scientific inquiry by way of identifying the independent, dependent, experimental, and standardized variables. Students' practice illustrating their data using both bar and line graphs and learn the appropriate graph to use for illustrating their data. Part I can be assigned as an individual or collaborative activity for middle school youth. Instructors teaching elementary school youth are strongly encouraged to only handle the naked egg during the experiment. Conversely, a class collaboration is recommended for the 3rd-5th graders. Part II of the activity provides the middle school youth with the opportunity to apply the scientific concepts learned during Part I to design and implement their own experiment and investigate the effects of one independent variable (i.e., sugar, vinegar, corn syrup, rubbing alcohol, cornstarch or baking soda) on a naked hen egg. The required time to complete Part I of the *Let's Journey through Osmosis with a Naked Egg* workbook is 2 hours. Part II requires 1 hour per day over a 3-day period. Open ended questions can be completed in class or assigned as homework. When refrigerated, naked eggs can last for up to 2 weeks (Spence, 2021).

Beneficial Health Impacts of Fruits and Vegetables Workbook. This hands-on, inquiry-based learning activity reaffirms the importance and benefits of eating fruits and vegetables. Students learn how red cabbage juice can be used as a pH indicator solution as well as the natural defenses of antioxidants against cellular oxidative stress by detecting the strength of antioxidants against free radicals in the presence of hydrogen peroxide. During this activity, the youth collect qualitative data by documenting the changes in color of solutions for various fruits and vegetables. They continue to expand their knowledge about scientific inquiry by identifying independent, dependent, experimental, and standardized variables; they learn the difference between qualitative and quantitative data and practice when to illustrate their data using a bar graph. The required time to complete the *Beneficial Health Impacts of Fruits and Vegetables* workbook is a total of 4 hours. During this experiment, students will have time between taking measurement to complete the worksheets in their workbooks. Instructors can divide this activity into two 2-hour, in-class sessions on two different days with students completing the open-ended questions in class or as homework (Spence, 2021).

Exploring the Link between Land Management, Plant Growth and Water Quality Using a Mini-Garden Model Workbook. Horticultural plants, grown specifically for human use, offer diversity to human diets and enhance the human living environment. This hands-on, multi-week activity allows students to continue practicing the scientific process while learning about the physical and chemical properties of soil, gardening practices, and the importance of water quality. This is a fun and practical activity for middle school youth to learn about techniques for growing food, the influence of water quality, and the implications they have on land management. During this activity, students will collaborate as a research team to create mini-garden models with the aim of investigating the practice of applying organic materials, such as turf grass clippings, leaves and other natural materials on plant growth as well as nitrogen leaching and water movement through a soil profile. Moreover, students will learn how the carbon to nitrogen (C:N) ratios of the organic materials influence the rate of nitrogen availability for plant uptake. This activity is designed for students to collect plant, soil and water quality data on a daily basis for up 19 days. At the end of the experiment, students will calculate the mean growth lengths, plot line graphs, analyze their results, and write down their explanations, discussions, and conclusions in their workbook. Additionally, this activity will enable students to self-reflect on what they learn. The required time to complete the *Exploring the Link between Land Management, Plant Growth and Water Quality Using a Mini-Garden Model* workbook is estimated as 19 days. Preparation DAY 0 requires 2 hours for students to conduct background research and plan their experiment. Preparation DAY 1 requires 2 hours to set up the experiment and conduct initial measurements. The required time to collect the daily measurements is 1 hour over per day over an 18-day period. For the final day of the experiment (DAY 19), 2 hours should be allotted to collect measurements, create the graphs, and complete the open-ended questions as homework (Spence, 2021).

Program Description and Delivery.

John Avery Boys and Girls Club. The DISCUSSION Network established a connection with the John Avery Boys and Girls Club of Greater Durham (BGCGD), the first African - American Boys and Girls Club in the United States. The Boys and Girls Club is a private, nonprofit organization that provides an afterschool program with specialized activities for youth during the traditional school year, primarily to a population of students meeting the criteria of underrepresented minorities in STEM and underserved "at-risk" youth (Boys and Girls Club of Durham and Orange Counties, 2017). The BGCGD's after school program occurs every weekday during the traditional school calendar year between 2:30 pm and 6:30 pm. The afterschool program offers several concurrent activities that focus on leadership development, academic success, computer literacy and coding, fitness and stress management, health and life skills, creativity and culture awareness (Boys and Girls Club of Durham and Orange Counties, 2017). The BGCGD youth attend public, public charter and private schools located in Durham County, North Carolina. Furthermore, the BGCGD was located approximately 2 miles from NCCU's campus; the facility has since moved to another location.

FEWLM was an ideal program for the elementary school youths attending the BGCGD, because the DISCUSSION Network goals align perfectly with the BGCGD's mission. DISCUSSION faculty from NCCU visited the 3rd – 5th grade class at the BGCGD afterschool program between March and April of 2018 over a 4-week period to implement the FEWLM curricula three days a week (Monday, Tuesday, and Wednesday) in two 2-week intervals. Each session began around 4 pm and did not exceed 2 hours. The sessions held at the BGCGD involving FEWLM consisted of two 2-hour sessions that allowed the following schedule for the first session: 1) workbooks handed out to participating students, 2) review of the workbook activity by the lead instructor, 3) distribution of activity relevant materials, and 4) a demonstration of the proposed activity by the lead instructor followed by a trial run by the students. The second 2 – hour session involved a review of the workbook and completion of the activity by the students. The elementary school youths who participated in the FEWLM activities were designated the NCCU DISCUSSION STEM Club.

The sessions at the BGCGD afterschool program were conducted by three African American female STEM

professors from NCAT and NCCU with years of teaching students from diverse socioeconomic and educational backgrounds. Dr. Porché Spence has a Ph.D. in Soil Science from North Carolina State University. As adjunct faculty, Dr. Spence teaches environmental science and natural resource conservation courses in the Department of Natural Resources and Environmental Design at NCAT, and general biology and environmental biology courses in the Department of Biological and Biomedical Sciences at NCCU. Dr. Tonya Gerald-Goins has a Ph.D. in Pharmacology and Experimental Therapeutics from the University of Maryland, Baltimore School of Medicine. As an associate professor in the Department of Chemistry and Biochemistry at NCCU, Dr. Gerald-Goins teaches a variety of chemistry and biochemistry courses. Dr. Kimberly Weems has a Ph.D. in Applied Mathematics from the University of Maryland at College Park. As an associate professor in the Department of Mathematics and Physics at NCCU, Dr. Weems teaches a variety of statistics courses. The three female African American STEM professors have motivated STEM and non-STEM undergraduate students to learn content.

This knowledge and ability of the aforementioned faculty enables them to effectively teach STEM using the FEWLM curricula. The workbooks allow students to experience the activities while their interaction with the URM scientists provides a tangible opportunity to see a possible future career. A Ph.D. is not needed to use these materials, even though they were developed by Ph.D. scientists. The FEWLM workbooks are designed to be clear and easy-to-follow so that elementary and middle school teachers, parents and STEM outreach instructors can guide students through the activities. Older students might complete some activities on-their-own with minimal supervision.

NCAT/NCCU "HydroPHonics" STEM Enrichment Summer Camp. The DISCUSSION Network established a connection with a non-profit organization, Alamance-Burlington Closing the Achievement GAP, Inc., located within the Alamance-Burlington County Public School System (ABSS). The mission of the Alamance-Burlington Closing the Achievement GAP, Inc., is to "promote raising the achievement levels of all students and closing the achievement gap of ethnic minority and lower socioeconomic students" (Alamance-Burlington School System, 2016). The DISCUSSION Network collaborated with Alamance-Burlington Closing the Achievement Gap, Inc. through ABSS to organize and implement a cost-free two-week "HydroPHonics" STEM Enrichment Summer Camp to increase scientific literacy and critical thinking skills using FEWLM. The selected URM ABSS student participants were rising 6th graders to rising 9th graders. One of the members of the Alamance-Burlington Closing the Achievement GAP, Inc. organization serves as the ABSS Director of Outreach Services and was instrumental in organizing the application process, transportation, and summer camp counselors as certified ABSS STEM teachers. The DISCUSSION Network provided University faculty (NCAT and NCCU), undergraduate counselors, professional development workshops, facilities, consumables and sustenance.

The two-week HydroPHonics Summer Camp was led by Drs. Gregory Goins and Tonya Gerald-Goins on the NCAT campus. Three workbooks were introduced and used, *Exploring Scientific Inquiry and Mathematical Thinking with Skittles*, *My Sprouting Bean Seed*, and *Let's Take a Biochemical Journey through Osmosis with a Naked Hen Egg*. The HydropHonic Summer Camp lasted two weeks and consisted of 40 URM middle school students that ranged from rising 6th to rising 9th graders; 80% male and 20 % female. There were five URM counselors (two African-American female educators from the Alamance – Burlington School System, one African-American female NCAT graduate student and two NCAT STEM undergraduates, both African-American STEM majors; one female and one male who was also a member of the football team. The students arrived on campus by 9:00 a.m. and assembled in an auditorium of Barnes Hall on NCAT's campus. Lead instructors reviewed the previous day's activities before presenting the current day's schedule. Students were then sent to two adjoining teaching labs at 9:30 a.m. Each student participant was required to wear safety goggles and a disposable lab coat; a lab safety course was given to all counselors and participants. Each student participant was given a workbook, which was reviewed by one of the lead instructors and any required materials. Student participants could then work according to the instructions given in the workbook. Students were also building a hydroponic system and a vivarium at each lab table. Lunch was scheduled from noon to 1:30 p.m. in the Williams Cafeteria on NCAT campus. The walk from Barnes Hall to Williams Cafeteria allowed students an opportunity to get fresh air, physical activity and an informal tour of NCAT's campus. After lunch, students returned to Barnes Hall to work on any incomplete tasks from the morning. Everyone assembled in Barnes Hall Auditorium for discussions and to watch short relevant videos. Some afternoons, students presented a brief overview of their work for the day or they listened to a STEM professor from NCAT. Students departed NCAT at 3:00 p.m. every day.

Data Collection. A modified version of the "Assessing Women and Men in Engineering" (AWE) pre-college outreach STEM activity surveys was administered in a paper form using student initials and birthdates as a unique identifier by the DISCUSSION Network instructors. These surveys were designed to be flexible for researchers to add and remove specific questions provided by AWE without compromising the validity of the survey. The pre-college outreach STEM

activity pre and post upper elementary school surveys were administered to the 3rd-5th grade youth at the beginning and end of the 4-week BGCGD NCCU DISCUSSION STEM club. The pre-college outreach STEM activity for middle school science surveys were administered at the beginning and end of to the two-week NCAT/NCCU DISCUSSION Network "HydroPHonics" STEM Enrichment Summer Camp. AWE pre-college outreach STEM activity assessments (NSF Grant # HRD – 0120642 and HRD - 0607081) are validated tools "designed to understand whether formal or informal educational activities are achieving the desired goals" and to survey youth participants about 1) attitudes regarding science, 2) educational background and experiences and 3) career ambitions (Assessing Women and Men in Engineering (AWE), 2008, 2010). To supplement the AWE surveys, a Student Background Information Sheet and Science Interest Questionnaire were given to elementary school youth at the BGCGD prior to beginning FEWLM.

Ethics Statement. This study was reviewed in accordance with federal regulations governing human subjects research and qualified as an expedited review study (NCAT IRB #17-0109).

Table 3. *Elementary school (afterschool program) and middle school youth (summer camp) participant demographics.*

FEWLM Participants (%)	Elementary School (n = 27)	Middle School (n = 26)
Gender		
Girl	33	24
Boy	67	76
Race and Ethnicity		
Asian	--	--
Black/African American	96	50
Hispanic/Latino and Spanish	4	19
Middle Eastern/Northern African	--	4
Native Hawaiian/Pacific Islander	--	--
Multiracial	--	27
Educational Training		
Public	30	85
Public Charter	66	--
Private	4	15
Post High School Graduation Plans		
Attend College	50	100
Attend Technical School	15	--
Get a Full-Time Job	15	--
Join the Military	12	--
Don't know	4	--
Other	4	--
Parents Graduated from a University or College		
Yes	71	82
No	5	11
I don't know	24	7

RESULTS

Youth Participants. A total of 55 youths were engaged in science inquiry using the FEWLM curricula; 27 elementary age (3rd – 5th graders) at the BGCGD afterschool program NCCU DISCUSSION STEM Club between March and April 2018 and 38 middle school age (rising 6th –rising 9th graders) participants in a two-week NCAT/NCCU DISCUSSION "HydroPHonics" STEM Enrichment Summer Camp (Table 3). Each participant fit the description of a URM in STEM; however, youth who self-identified as African - Americans represented the largest demographic percentage at the BGCGD afterschool program (96%) and the NCAT/NCCU DISCUSSION "HydroPHonics" STEM Enrichment Summer Camp (50%). Furthermore, the majority of the youth participants self-identified their gender as male (60%). The elementary school youth participants predominantly attended public charter schools (67%) in Durham County, North Carolina, while the middle school youths attended public schools (85%) in Alamance-Burlington, North Carolina. A large percentage of the youth participants came from families with parents who were college graduates (71% after school program and 83% summer camp participants).

Impact of FEWLM on Interest in Science and Scientific Career.

Elementary School Youth. Prior to engaging with FEWLM, 50% of the elementary school youth at the BGCGD afterschool program had aspirations of attending college after high school (Table 3) and 67% of the youth wanted to enter non-science professions as an adult. Even though a small percentage of the youth aspired to have a STEM career (Table 4), many self-reported they enjoyed science (56%) and agreed with the statements "I am good at science" (86%), "I am good at math" (75%) and "I am good at engineering" (60%). Despite their confidence in performing science, only 31% of the youth declared science and 52% of the youth

Table 4. *FEWLM influence on science interest and career aspirations for elementary school (afterschool program) and middle school youth (summer camp).*

Participants (%)	Elementary School (n = 26)			Middle School (n = 27)		
	Yes	*No*	*Don't know*	*Yes*	*No*	*Don't Know*
I look forward to science class in school.						
Pre Survey	61	39	--	87	13	--
Post Survey	56	44	--	96	3	--
If you go to college, do you think you will pursue a career in a science-related field?						
Pre Survey	40	20	40	46	23	31
Post Survey	16	36	48	46	12	42
In your future, do you think you want to be a scientist?						
Pre Survey	20	45	35	11	50	39
Post Survey	24	52	24	22	40	38

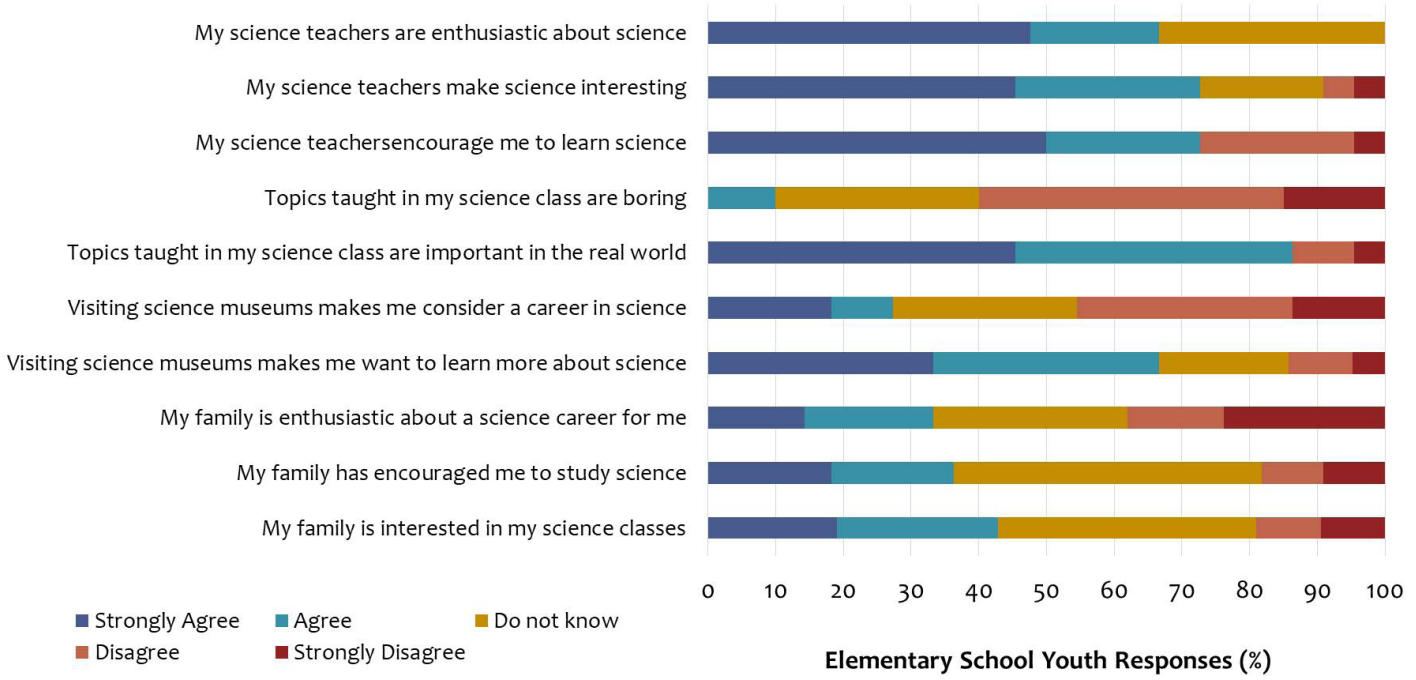

Figure 4. Pre-FEWLM Elementary School Youth Interest in Science.

declared math was their favorite subject in school. Many believe they are creative (86%) and enjoy learning how things work. When asked "have you carried out a scientific experiment in your classes at school," 56% of the elementary school youths responded "yes" and 8% responded "I don't know."

Elementary school youths self-reported that family interest in science, family encouragement to study science, and family enthusiasm about a science career was relatively low (Figure 4). Informal science learning experiences, such as visiting museums and exhibits, seemed to help pique their interest in science; however, these experiences did not increase the likelihood for considering a career in science. Despite the fact their teachers made science interesting and encouraged them to learn STEM, the majority of these youths had very little interest in becoming a scientist. Overall, they enjoyed learning science and their attitude about scientists was positive (Figure 4). These youths understood the importance of science in the real world, recognized that scientists help make people's lives better (72%), and stated they would enjoy a job helping to protect the environment (71%), yet only a few aspired to become a scientist (Table 4). Unpublished draw-a-scientist data suggest that many elementary youth associate scientists with working with chemicals in the lab.

After engaging with the FEWLM workbooks, the elementary youths self-reported that FEWLM helped them understand science better, motivated them to want to work harder in school, and increased their confidence in doing science (Table 5). Furthermore, the survey captured a slight decrease in elementary school youths looking forward to attending science class and their interest in pursuing a science related career; however, their interest in becoming a scientist slightly increased (Table 4). Only 38% reported they wanted to try to redo the FEWLM activities at home. Overall, the elementary school youth in the BGCGD after school NCCU DISCUSSION STEM Club (78%) stated they would recommend the FEWLM curricula to their friends.

Middle School Youth. Prior to engaging with FEWLM, all of the middle school youth participating in the NCAT/NCCU DISCUSSION "HydroPHonics" STEM Enrichment Summer Camp aspired to attend college after graduating from high school (Table 3). Among these middle school youths, 46% think they will pursue a career in a science related field; however, only 11% think they want to become a scientist. Several middle school youths self-reported they always get good grades in science (55%) and math (60%), yet many agree that science is a difficult subject (48%), especially when it involves math (48%). Even though the middle school youth had very little interest in becoming a scientist, many look forward to attending science class (87%).

After engaging with the FEWLM curriculum at the NCAT/NCCU DISCUSSION "HydroPHonics" STEM Enrichment Summer Camp, the middle school youth participants reported that FEWLM helped them understand science better, motivated them to want to work harder in school, and increased their confidence in doing science (Table 5). There was an increase in the percentage of middle school youth looking forward to attending science class (+9%) and thinking about becoming a scientist (+4%). Moreover, the middle school youth reported FEWLM increased their interest to

Table 5. *Post FEWLM evidence from the AWE pre-college survey.*

Impact of FEWLM (% Yes Response)	Elementary School (n = 26)	Middle School (n = 27)
Understand science better	100	97
More confident in your ability to succeed in science	86	90
Decide to work harder in school	96	97
Make you want to try to redo the activities at home	38	77
Increased my interest in studying science in college	--	94
Led me to better understand my career goals	--	87
Made me think about what I will do after graduating from high school	--	94
Increased my confidence in my ability to participate in science projects and activities	--	94

Note: Likert-type responses from the middle school youth survey were re-coded as Yes (slightly, moderately, a great deal) and No (not at all) to be consistent with the elementary school youth survey.

study science in college, helped them to better understand their career goals, made them think about what they will do after graduating from high school, and increased their confidence in their ability to participate in science projects and activities (Table 5). Overall, most participants attending the NCAT/NCCU DISCUSSION "HydroPHonics" Summer Enrichment Camp (94%) would recommend the FEWLM curricula to their friends, and several were interested in trying the FEWLM activities at home (77%).

The data in Table 5 have been recoded and updated so that scoring is consistent for the two groups of students. Likert-type responses from the middle school youth survey were re-coded as Yes (slightly, moderately, a great deal) and No (not at all) to be consistent with the elementary school youth survey. Table 5 shows the noticeably large discrepancy between the percentages of elementary and middle school students who wanted to repeat the experiment at home is (38% for elementary school students and 77% for middle school students). Further investigation is needed to understand if this difference is influenced by age, socioeconomic status, academic background or other factors. Overall, these percentages represent the lowest scores for both groups of students.

DISCUSSION AND SUMMARY

A fortuitous outcome for the DISCUSSION Network core team was to identify, develop and implement a scaffolded low-cost, inquiry-based Food, Energy, and Water Learning Module (FEWLM) that provides a culturally relevant learning experience for "at risk" underrepresented elementary and middle school youth while encouraging them to become interested in STEM careers. For example, once students create the naked egg, students measure the mass of the egg after sitting in hypertonic salt or sugar solutions over time. The effects of the solution on the mass of the egg are correlative of a "cell" in a person diagnosed with hypertension or diabetes, two metabolic disease states that disproportionately affect members of URM ethnic groups.

Data collected from survey instruments suggest FEWLM is effective for teaching and positively promoting scientific literacy and quantitative skills to broaden the participation in STEM across socio-economic barriers for elementary and middle school youth. These low-cost, inquiry-based learning modules provide a scaffolded curriculum for youth to learn, practice, and apply the scientific inquiry while learning concepts associated with the FEW nexus (Figure 5). Through FEWLM, students learn that scientific concepts associated with the food, energy and water nexus are not isolated facts but interconnected and interdependent systems with complex solutions that require systems thinking. Evidence from the elementary and middle school youth indicates FEWLM made a positive impression on the youth and increased students' interest in STEM, their perception of its value to their lives, and confidence in their ability to participate in STEM.

The youth have some understanding of STEM fields. In underrepresented communities, "traditional" scientific field most familiar are medical doctors, chemists, biologists, and engineers. Less familiar scientific careers are soil scientists, ecologists, astronomers or astrophysicists, etc., because they do not often see people in these fields in their communities. The word "scientist" is broad and can represent many different fields. During our sessions, the youth would discuss their career ambitions and talk about specific scientific professions.

The goal of this project was to provide a low-cost, high-quality science curriculum that has relevance and is practical to the lives of URM students in K-12 grades. This has been achieved by explicitly embedding concepts in learning materials that stimulate thinking about solutions to food insecurity, human and environmental health issues, and threats to conservation and Earth ecosystem balance. Although the target group for this curriculum was URM students, it should have value and wide appeal beyond just this group.

FEWLM promotes learning science by performing the scientific process to conduct research experiments, which aligns with the Next Generation Science Standards. FEWLM workbooks are designed for these youths to collaborate self-sufficiently as a group of "scientists in training," which teaches team-building skills. Furthermore, FEWLM focuses on solving real world problems using an interdisciplinary approach with an emphasis on data interpretation and promotes self-reflection as learning mechanisms.

Advantages and Disadvantages of Implementing FEWLM. There are advantages and disadvantages for instructors who adopt FEWLM to teach scientific inquiry. FEWLM provides affordable and student-centered learning

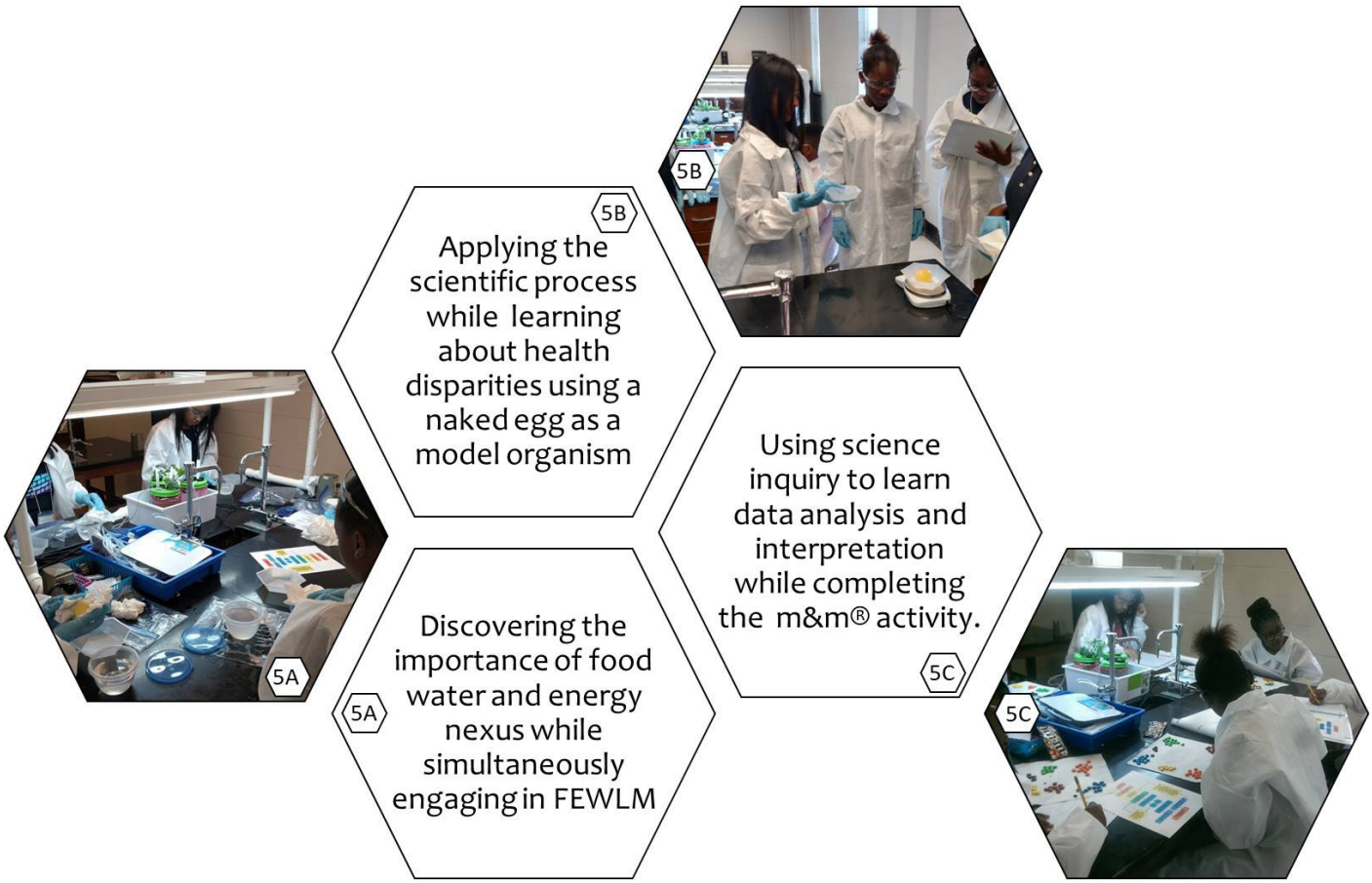

Figure 5. Middle school youth participants learning science inquiry via FEWLM.

for elementary and middle school youth to learn that science is a process and supported with data and other forms of evidence. These workbooks are designed for instructors who teach science inquiry in both formal and informal educational settings. There are no pre-determined answers. Every time the FEWLM workbooks are implemented, a new data set is generated. The cost for adopting these workbooks is less than $300 for a class size of 30 students, with the cost for executing these modules during subsequent years becoming lower because several items on the materials lists can be reused. Moreover, the cost to use all 6 of the FEWLM workbooks in a class setting with a lower number of students would be even more affordable.

The FEWLM budget does not account for the cost to print each student their own workbook. These workbooks are lengthy, with the number of pages for a given activity ranging from 14 to 31, and requiring each student have their own copy to complete the activity. For instructors at institutions with printing restrictions, the length of the workbook could be a deterrent for selecting to use FEWLM. As a substitute for printing individual workbooks, instructors can print one copy for each group, and the students can complete the activity in composition notebooks. If instructors plan ahead, 100-sheet composition notebooks, which are quite reasonable in cost during the "back to school" sale, can be included on the parent's school list at no additional cost for instructors. Furthermore, instructors can use the composition notebook as an opportunity to teach elementary and middle school youth the purpose and concept of using laboratory notebooks as a scientific tool.

Most school systems have constraints regarding instructional time and topics to cover during an academic year. Third through eighth graders enrolled in public schools typically receive approximately 33 hours of school per week (Hoyer and Sparks, 2017). On average, third graders in public school spend 2.9 instructional hours per week learning science while the science instructional time for eight graders is 4.3 hours. Private elementary and middle schools spend less time teaching science than public schools (Hoyer and Sparks, 2017). Therefore, it could be challenging for teachers to complete all of the FEWLM workbooks because of the length of time required to complete all the activities could interfere with instructional time dedicated to other subjects, such as reading. Nevertheless, teachers could use FEWLM as a mechanism to indirectly practice reading, writing, and mathematics while increasing the instructional time allotted for science.

Study Limitations. The BGCGD after school program and NCAT/NCCU "HydroPHonics" summer camp were not designed to fully measure the comprehension of the subject matter; therefore, a pre/post-assessment was not administered to measure learning gains. The AWE survey instruments implemented did not included open-end questions to allow the youth to explain their answers. Furthermore, due to competing activities during the BGCGD after school program and flexible pick-up times, the number of youth completing the FEWLM workbooks varied each day making it difficult to keep accurate attendance records. As a result, it was challenging to efficiently evaluate the comprehension of the subject matter using the associated grading rubrics. Even though the summer camp was structured to be a day-long program and the participants were able to dedicate more time completing the activities, the workbooks were not collected and evaluated to determine comprehension of the subject matter because the middle school youth were encouraged to take their workbooks home and continue the experiments. They were not instructed to return their workbooks to evaluate comprehension and learning outcomes. Attendance was not taken at the NCAT/NCCU "HydroPHonics" summer camp.

In summary, FEWLM is an affordable approach to teaching STEM. Evidence suggests that low-cost interventions aimed at developing a sense of connection, a growth mindset, and the utility goals and values have generated great benefits for underrepresented minority students. Although encouraging, the evidence presented in this study is limited in generalizability, so further research is needed to replicate and extend it to other informal and formal educational settings. Through affordably programmed science content and curricular materials developed, the DISCUSSION Network is connecting STEM learning to the immediate, relevant, and personalized life experiences of students from a range of socio-economic backgrounds, resulting in increases in science interest and literacy, and this approach may be an effective stimulus for driving social change that improves the participation of underrepresented minorities in STEM.

ASSOCIATED CONTENT

The elementary and middle school Next Generation Science Standards learning objectives for each FEWLM workbook is available for download as supplementary materials. Educators interested in adopting FEWLM can access it at the following QUBES DISCUSSION website: https://qubeshub.org/publications/2287/1.

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Author Contributions

The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript.

ACKNOWLEDGMENTS

We would like to thank the youth participants and staff at the Boys and Girls Club of Greater Durham and Orange County as well as the faculty, staff and students of the Alamance-Burlington School System.

FUNDING SOURCES

This research is supported by the National Science Foundation Award Numbers 1649255 and 1649263.

ABBREVIATIONS

ABSS: Alamance-Burlington County Public School System; AWE: Assessing Women and Men in Engineering; BGCGD: Boys and Girls Club of Greater Durham; DISCUSSION: Diverse and Integrative STEM Continua Using Socio-environmental Systems In and Out of Neighborhoods; FEW: Food, Energy, and Water; FEWLM: Food, Energy, and Water Learning Module; NCAT: North Carolina A&T State University; NCCU: North Carolina Central University; NGSS: Next Generation Science Standards; NSF INCLUDES: Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science; STEM: Science, Technology, Engineering and Mathematics; URM: Underrepresented Minorities

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