CITIZEN SCIENCE:
THEORY AND PRACTICE

How Do Teachers Learn and Engage with Climate Change? An Examination of the *Shade Our Schools—Leaves Are Cool!* Citizen Science Program

CASE STUDY

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ABSTRACT

Schools are the best venue for increasing climate literacy, and teachers are ideal channels to convey meaningful information to students. However, most teachers have not participated in significant learning experiences or training related to climate change. Informed and well-prepared teachers feel more confident to debate or talk about this subject. Participation in active research provides teachers with a sense of expertise that makes them more confident to teach this topic. By participating in the Shade our Schools—Leaves are Cool! citizen science project developed for the Fairchild Tropical Botanic Garden's Fairchild Challenge in South Florida, students and teachers conduct a series of experiments to explore how different plant species will fare under climate change scenarios. We surveyed 100+ elementary and middle school teachers during a period of three years to evaluate teacher knowledge gained over the duration of the annual Challenge and the impact of the project in schools. This project has been a successful experience for our participants to learn and engage with climate change–related topics and plant physiology.

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INTRODUCTION

One of the most pressing problems facing the modern world is climate change. An understanding of global climate change, including its causes and possible mitigation strategies, will increase awareness and will potentially influence behavior to help minimize potential negative effects of altered climates. The interest in climate change education has increased rapidly as reflected in the number of papers published on the subject: only 12 in the 1990s, 433 in the 2000s, and 1,489 from 2010 through 2015 (Monroe et al. 2019). However, of the total amount of papers related to climate change/environmental education, only 49 described and assessed real intervention programs. Furthermore, climate change does not appear in the educational standards of every US state; in some states, it is optional, outdated, and/or intentionally weakened like in Texas (Choi-Schagrin 2022). For example, a study that collected data from 1,500 public middle school (grades 6–8, ages 11–13) and high school (grades 9–12, ages 14–18) science teachers from all 50 US states showed that on average only one to two hours per year are dedicated to teaching this important subject, if it is taught at all (Plutzer et al. 2016). Even when this interdisciplinary subject is taught, it is usually only addressed by Earth Science teachers (Wise 2010). Given the complexity of this topic, we cannot rely on media or similar sources for climate change education (Dunwoody 2007), and need improved, interdisciplinary climate change education in schools.

Schools should be a venue for increasing climate literacy, and teachers are the perfect channels to convey the relevant information to students. Unfortunately, teachers' training about environmental topics is limited, especially concerning climate change. Many educators in the US self-report that they do not have the skills or knowledge to deliver an accurate curriculum about climate change (Plutzer et al. 2016). An increase in content knowledge, specifically in STEM areas, is associated with an increase in teachers' confidence with these subects and success in teaching them (Bursal and Paznokas 2006). Successful instructional approaches provided by well-prepared teachers have a significant impact on students' achievements (Darling-Hammond 2000). However, STEM training in the US in a typical education program for K–8 teachers generally entails only two semesters of math and two semesters of science courses (Fulp 2000), and many are never exposed to scientific research projects (Silverstein et al. 2009). This can lead to a decrease in the quality of the instructional practices, negatively affecting students' achievements in science (Francisco and Celon 2020). Despite these problems, most of the educational research in this field is focused on how to teach students about climate change and not on how to train teachers to instruct.

Even when most teachers agree that climate change should be taught in classrooms, many of them still see this issue as being "two sided," with uncertainty about even the existence of global climate change (Wise 2010). They may also not appreciate that climate change is a social, political, and economic issue as well as a scientific one. For example, most non-science teachers only informally discuss this topic, and many do not address it at all. Even some life science teachers report that climate change is beyond their curriculum standards, since this subject is associated with Earth Science (Wise 2010). A survey of Colorado (United States) public school science teachers revealed that 17% of them have not participated in any learning experiences related to climate change; among the teachers who had learned about climate change, the most-commonly used methods were websites, magazines, and books. Most of the teachers did not report participating in real-world research as a way of learning about climate change (Wise 2010). Another issue is that climate change is often introduced at the high school level rather than in middle or elementary school (kindergarten to 5th grade, ages 5–10) (Wise, 2010), even though early instruction of the subject should be a priority.

At the University of Miami (UM), in collaboration with Fairchild Tropical Botanic Garden (FTBG), we have created a citizen science program in which students collect data to assess how plants are going to react to climate change in the future. Here we use our experiences with the Shade our Schools—Leaves Are Cool! citizen science program to test the hypothesis that participation in a citizen science activity increases teachers' scientific knowledge, specifically in the conceptual understanding of plant physiology/impacts of climate change. We aim to answer the following research questions: (1) How does participation in a citizen science program impact teacher knowledge about plant physiology/climate change in the context of Miami? (2) What are the challenges and best practices associated with implementing citizen science programs within the K–12 educational system in Miami? (3) Can a citizen science program motivate teachers to learn about climate change?

LITERATURE REVIEW

CHALLENGES TO LEARNING ABOUT CLIMATE CHANGE

Political ideology

Creating climate change education programs is particularly challenging owing to the complexity of the controversy regarding the ethics and values associated with this issue (Monroe et al. 2019). Previous studies in the US and Australia have shown that political party affiliation/ideology, which also affects politics of school boards and curriculum development, is a powerful predictor of climate change perception (Fielding et al. 2012; Hess and Maki 2019). Teachers who perceive this as a real issue will better shape students' beliefs about the reality of climate change (Stevenson et al. 2016). Learning about climate change may be a powerful tool to weaken the relationship between ideology and climate change beliefs.

Misconceptions

One of the factors most negatively affecting teachers' instruction about climate change is lack of prior knowledge about the topic (Seroussi et al. 2019). This lack of knowledge is evident when most of the teachers think that "there is substantial disagreement between scientists about this topic" or that "the ozone layer causes warming" or that they "somewhat disagree with the fact that global warming is caused by humans" (Wise 2010). Liu et al. (2015) described that even after attending a professional development program about climate change, secondary school science teachers still conflated global warming with problems caused by ozone layer depletion, a very common misconception.

Curriculum

A primary barrier for educators to teach about climate change is that this topic often does not fit in their established curriculum (Wise 2010). The introduction of non-curricular topics disrupts the planned learning sequence and creates time constraints to prepare students for state exams. It may burden teachers with additional preparation, in addition to students' resistance to learning non-curricular material.

STRATEGIES TO ENGAGE TEACHERS IN CLIMATE CHANGE LEARNING

To engage teachers in climate change learning we need to understand their motivations. The expectancy-value model of achievement motivation postulates that "individuals' expectancies for success and the value they have for succeeding are important determinants of their motivation to perform different achievement tasks, and their choices of which tasks to pursue" (Wigfield and Eccles 2002). According to McNeal et al. (2017), teachers' motivations are divided into five aspects: (1) expectancies of success based on how prepared teachers feel to debate or talk about the subject; (2) teaching philosophy, which refers to whether teachers identify themselves as educators or scientists; (3) intrinsic values, which reflect how well the content aligns with personal values and/or political views; (4) utility values, which mean, for example, that the content aligns with national or state standards; and finally (5) cost value, or the potential negative impact of teaching this topic on the teaching environment and/or students' motivation. As part of the academic community, universities can address the first, second, fourth, and fifth aspects of teachers' motivation, and create programs that bolster teachers' confidence when teaching about climate change. Universities are uniquely positioned to involve teachers in ongoing research, thereby enhancing their knowledge on specific subjects and fostering a sense of belonging to a research team. This approach also affects the cost-value aspect, as well-prepared teachers can offer improved instructional practices that enhance student motivation. We, as university partners, can also influence utility value by including state benchmarks along with our science activity. The third aspect is more related to personal views.

Monroe et al. (2019) identified two strategies to ensure success in climate change education: (1) The information should be personally relevant to learners, and (2) intervention should engage them. Students tend to learn what is personally relevant for their context. For example, students in Miami may be more interested in learning about climate change if lessons discuss vulnerability of South Florida's coast to sea level rise and the cost of adapting to this threat. Climate change can also become personally relevant for students when they are the ones collecting the data necessary to demonstrate or understand the processes. For example, Hallar et al. (2011) described how students' knowledge about climate change significantly increased after a hands-on experience collecting meteorological data at the Storm Peak Laboratory in Colorado. Monroe et al. (2019) described several strategies for students' engagement such as the use of debates, audiovisuals, role-plays, drawings, and inquiry-based activities. The authors emphasized the importance of students' interactions with science and scientists as a way of engaging and increasing climate literacy, and explained how the teachers involved in real-world research gained confidence to support students learning about climate change.

Climate change could be used as a tool to teach other subjects included in the curriculum and standards. Teachers who are considered more involved convey, in focus groups, that teaching climate change is an effective way of teaching the process of science (McNeal et al. 2017). This approach could be transferred to less motivated teachers, who may see increased value in teaching about climate change if it helps them to develop their process-of-science curriculum.

Teachers can also learn very effectively from other teachers (McNeal 2017). As such, another potential strategy to increase teachers' motivation is to create interdisciplinary science projects for which teachers integrate knowledge from different fields to undertake an investigation. The issues of climate change transcend the field of hard sciences and benefit from expertise in other fields like political science, economics, social sciences, arts, and communication. Inviting teachers from different areas to participate in climate change projects can encourage them to include this topic in their curriculum even though it might not be required by state science standards.

Participation in active research

Participation in active research is a powerful mechanism to enhance teachers' experiences when learning about climate change. McNeal et al. (2017) described how active research provides teachers with a sense of expertise and motivation to teach the subject. Collecting their own data and creating their own representations of climatic processes can increase teachers' "metarepresentational competence," (MRC) which may be crucial for their learning and motivation (diSessa 2004). It is usually through universities' outreach programs that teachers can connect with researchers. Currently, the NSF has a funding program that supports teachers to get involved in real research taking place at different universities, colleges, national laboratories, and botanic gardens. However, some of these programs are not hands-on experiences and most are not related to climate change.

Citizen science encompasses the active involvement of the public in scientific research activities, generating new insights and knowledge for the betterment of both science and society (Haklay et al. 2021). Active participation in citizen science projects has shown to be effective in the conceptual learning of science, with high knowledge retention rates and the development of the participants' critical thinking and communication skills (Araújo et al. 2022). The effectiveness of these programs in the field of ecology has been demonstrated by an increase not only in content knowledge, but also in the awareness of the human impact on nature (Branchini et al. 2015). Furthermore, the socio-emotional development and working memory of individuals is improved by their participation in citizen science (Hirschenhauser et al. 2023). Educators recognize the value of participating in these projects and the impact they have on learning (Aristeidou et al. 2021). Engaging in interactions with active scientists and participating in research-based professional development programs can serve as effective strategies to promote engagement in climate change education and enhance teachers' pedagogical skills in this domain.

Many of the experienced teachers who are equipped with the pedagogic tools to incentivize students' learning about climate change completed their education when climate change was not a conspicuous and pressing topic (McNeal 2017). Therefore, these teachers have not been trained on how to effectively address the topic of climate change with their students. Teachers in the McNeal (2017) study indicated that they learned about climate change from the internet/newspapers/books, workshops, personal science/research background, and collaboration with other teachers and scientists. Collaborations with other teachers and scientists was also described to be an effective method to encourage less motivated teachers (McNeal et al. 2017), and accordingly, more motivated teachers often describe themselves as scientists as well as educators. This teaching philosophy, which is enhanced by the interaction with active scientists, promotes student/teacher engagement in climate change research (McNeal et al. 2017). Hestness et al. (2014) also identified research-based professional development as an effective approach for climate change education. They highlighted the importance of the collaboration among teachers and climate scientists, news outlets, and education researchers.

One problem that arises from this idea is how to engage less motivated teachers in authentic research. Usually, those that participate in universities' outreach activities or citizen science programs are already motivated teachers that purposely want to increase their knowledge on the subject. We also need to reach those teachers who, because of exhaustion, lack of confidence, time, experience, or political affiliations do not volunteer to participate in programs that are crucial for their training and motivation.

Complementary educational curricula using state science standards that teachers can use with their students, facilitating the instruction instead of creating more work for them, could help new as well as veteran teachers to engage in climate change education. Our target should be to support, engage, and motivate teachers to pursue this knowledge and pass it on to several generations of students.

Research shows that citizen science activities are highly engaging for participants (Schuttler et al. 2019). Considering this, we can anticipate that citizen science could serve as an effective tool for training teachers in climate change–related topics. Taken together, these factors suggest that we must focus on teachers' learning and engagement as part of the comprehensive evaluation of any citizen science program.

In response to this need, we have created the Shade our Schools—Leaves are Cool! citizen science project to collect data for ongoing climate change research and to engage teachers and students in scientific research. In this study, we used data from the Shade our Schools—Leaves are Cool! project to test the hypothesis that participation in a citizen science activity increases teachers' scientific knowledge, specifically in the conceptual understanding of plant physiology/impacts of climate change. We also describe here the strengths and barriers to participation in these kinds of projects, as well as teachers' motivations to get involved.

MATERIALS AND METHODS

SHADE OUR SCHOOLS—LEAVES ARE COOL! CITIZEN SCIENCE PROJECT

As temperatures increase due to global warming, it is increasingly important to understand how temperature affects plant performance. At UM's Jungle Biology laboratory, we assess the traits and mechanisms driving variations in leaf thermoregulatory properties and temperatures. This knowledge can be used to help inform management and conservation strategies. In order to screen as many species and traits as possible, we have developed the Shade our Schools—Leaves are Cool! citizen science project. In this activity, elementary and middle school students conduct a series of simplified but realistic experiments to see how leaf traits and behaviors affect leaf temperature. This activity was developed in collaboration with the Fairchild Tropical Botanic Garden (FTBG) as part of the Fairchild Challenge (FC) competition, and it merges key science topics such as Climate Change and Plant Physiology (Supplemental File 1: Florida State Academic Educational Standards).

The FC is a free, standards-based interdisciplinary environmental science outreach program that serves more than 125,000 PreK–12 students annually across South Florida, and is fully integrated into Miami-Dade County Public Schools (M-DCPS) pacing guides. This is done through a series of challenges designed to help augment existing curricula and support student learning (Fairchild 2021).

The Shade our Schools—Leaves are Cool! citizen science project was active for three academic years (2019–2020, 2020–2021, and 2021–2022), henceforth referred to as Years 1, 2, and 3. Each academic year, teachers and students had different research goals, and the project has reached different education levels (Supplemental File 2: Project goals). Due to COVID-19, year 2 was "My School Online," and this challenge was designed for remote distance learning. The project was implemented at students' homes or nearby areas.

The project took place over the course of the academic year. Best entries are evaluated by a panel of independent judges, and winning entries are awarded at the end of the school year. Teachers were provided with the materials to complete the challenge.

Finally, students had to present a journal with their results, where they not only included data but also reflections, drawings, sketches, and pictures. Students were judged not only based on their research quality, but also on their artistry/technical abilities and writing skills. This compelled teachers from different areas to work together, and encourages teachers to learn from fellow teachers.

PARTICIPANTS AND CONTEXT

M-DCPS, home to the majority of the Fairchild Challenge participants, is part of an international community in which more than 50% of the population is foreign-born and has one of the highest poverty rates in the US (U.S. Census Bureau, 2022). Miami "faces the largest risk of any major coastal city in the world," a consequence of climate change. (Raimi et al. 2020, page 21). These aspects present additional challenges that we need to comprehend and tackle when working with this community.

Supplemental File 3: Survey participants, shows the number of teachers who answered each questionnaire. It is important to note that not all of these teachers responded to every question, resulting in fewer responses for certain questions compared with the total reported in the table. The participation numbers in our teacher workshop and in the program in general are higher than those indicated here, as not all teachers completed the questionnaires. Please refer to the actual participation numbers in Supplemental File 4: Participation.

The teachers who signed up were a self-selected group that we recruited during a teacher luncheon, which is celebrated at FTBG at the beginning of each academic year. They actively engage with their students and undergo training to conduct experiments within their schools. Our surveys conducted during years 2 and 3 reveal a diverse group of participating teachers (Supplemental File 5: Participants background).

PARTICIPATION IN THE CHALLENGE

The Shade our Schools—Leaves are Cool! Project was highly popular among South Florida's schools, which is reflected in the number of students and teachers that have submitted their work (Supplemental File 6: Participation and data collection). We must note that during Year 2 we saw a decrease in submissions due to COVID-19, and that middle schools typically have less participation than elementary schools.

TEACHER TRAINING WORKSHOP DESIGN

The most important aspect of the program was to involve teachers and students in authentic ongoing research because it is a successful tool to bring relevancy to the subject of climate change while emphasizing the scientist identity of teachers (McNeal et al. 2017). The teacher training workshops were annually held in October of each academic year at FTGB and lasted three hours. In these teacher training workshops, we provided teachers with an overview of our laboratory´s most current research and how the Shade our Schools—Leaves are Cool! project supports critical data needed by The Jungle Biology lab. Training included talks provided by Dr. Kenneth Feeley and Dr. Timothy Perez, recognized leaders in global change biology. Guest speakers gave an overview of climate change and plant responses to help workshop participants see how the Shade our Schools—Leaves are Cool! project addresses these larger topics. Teachers were encouraged to reach out to us for any further questions and misunderstandings. This element is key to the project: the connection between schools/teachers and scientists.

Teachers are usually not convinced about the quality and usefulness of the data contributed by citizen scientists (Aristeidou et al. 2021). Considering this, each fall we summarize the results from the previous years and update the teachers on the most interesting findings from previous years.

In addition, we have carefully reviewed all State benchmarks (Supplemental File 1: Florida State Academic Educational Standards) for each grade and each subject to select those that align with our project. Each year, we provide that list to all the teachers to facilitate the insertion of the program in their curriculum, even when the subject is not explicitly required to be taught by the state.

Teachers are also trained on data collection protocols and analyses outside in small groups. The Fairchild Challenge staff led further training to ensure entries met the requirements. One of the most important goals of our workshops was to make the teachers feel confident in how to conduct the experiments, so they were able to successfully pass their knowledge to the students. This also supports their self-identification as a scientist. During our second year, the teacher training workshop was held online to follow COVID-19 safety measures. Additional resources available were videos and presentations (some in Spanish) created specifically for each year's challenge.

DATA COLLECTION

Overview

In order to measure the content knowledge gain of teachers, we created pre- and post-questionnaires that were administered during our teacher training workshop. We describe these surveys in more detail in the section entitled "Workshop questionnaire surveys." These questionnaires were analyzed using quantitative statistical methods. This allowed us to answer our first research question: *"How does participation in a citizen science program impact teacher knowledge about plant physiology/climate change in the context of Miami?"*

We employed qualitative methods, specifically a deductive thematic analysis approach, guided by the theoretical frameworks described by McNeal et al. (2017) regarding teachers' motivations and Monroe et al.'s (2019) successful strategies for teaching climate change to collect and analyze data. We designed end-of-the-year questionnaires with relevant questions to address these points. The end-of-the-year questionnaires also provided valuable insights into the strengths and challenges associated with the program. End-of-the year questionnaires are described in more detail in the eponymous section. These qualitative methods served to answer our second and third research question: "*What are the challenges and best practices associated with implementing citizen science programs within the K–12 educational system in Miami?" and "Can a citizen science program motivate teachers to learn about climate change?"*

For content knowledge questions (quantitative analysis), we primarily used multiple-choice questions because they are better suited for collecting and analyzing numerical data, reducing ambiguity and subjectivity, and allowing respondents to answer more quickly.

For our qualitative analyses, we mostly used open-ended questions that are capable of eliciting more detailed and diverse responses. These types of answers work better with a deductive thematic approach. We used a deductive thematic approach with a thematic framework from McNeal et al. (2017) and Monroe et al. (2019) and aim to validate or extend these theories.

Workshop questionnaires

To answer our first research question, *"How does participation in a citizen science program impact teacher knowledge about plant physiology/climate change in the context of Miami?"* we collected data at the beginning and at the end of the workshop. Data were collected via Mentimeter (Year 1 and 2) and Qualtrics (Year 3). Mentimeter and Qualtrics are platforms that allow creating and distributing surveys. We used Mentimeter because it is ideal for real-time interaction and engagement. We later switched to Qualtrics since it is a more comprehensive tool for analyzing structured survey and research data. Supplemental File 7: Year 1 Workshop questionnaire, Supplemental File 8: Year 2 Workshop questionnaire, and Supplemental File 9: Year 3 Workshop questionnaire, show the pre- and post-workshop questionnaires.

The workshop's pre- and post-questionnaires allowed for statistical analysis to determine whether or not teachers increased their content knowledge in the area of climate change. We hypothesized that our training significantly increased teachers' knowledge in that area.

We electronically sent the same content questions to evaluate knowledge at the end of the year, but we received very few responses. This limited the possibility for further analysis. While we were able to administer end-of-the-year questionnaires during teacher workshops held at FTBG, we were unable to include content questions in them due to time constraints.

End-of-the-year questionnaires

The end-of-the-year questionnaires allowed us to gauge the perception of teachers about their learning, while also enabling us to address our second research question: *"What are the challenges and best practices associated with implementing citizen science programs within the K–12 educational system in Miami?"* In all three years of the program, the final surveys asked about the strengths and challenges of the program (Supplemental File 10: End-of-the-year questionnaires). During Year 3, we added questions regarding teacher collaboration, student learning, participation in active research, and motivations (Supplemental File 10: End of the year questionnaires). These helped us to answer our third question: *"Can a citizen science program motivate teachers to learn about climate change?*

The questionnaires and content question keys were formulated by researchers from the Jungle Biology laboratory at UM and subsequently refined by educational department staff from FTBG. In conjunction with the primary author of this manuscript, an auxiliary evaluator from the FTBG Education department participated in the assessment of the questionnaires. This individual underwent comprehensive training, consisting of two instructional sessions conducted by experts from both UM and FTBG.

DATA ANALYSIS

Quantitative

To answer our first research question, *"How does participation in a citizen science program impact teacher knowledge about plant physiology/climate change in the context of Miami?"* we used content questions. For the content questions evaluated in the annual teacher training workshops (Year 2 and 3), we calculated the total score for each teacher for the pre and post questionnaires. We were able to match pre and post responses for 12 teachers in Year 2 and 12 teachers in Year 3, based on the type of school they represent, the subject area they teach, and how many years they have been teaching. Combinations of these answers created unique identifiers that allowed us to match pre and post test scores. For future studies, we recommend asking participants to create a unique identifier that allows for confident tracking and matching of their pre-assessment responses with their corresponding post-assessment results. We proceeded with a one-tailed Wilcoxon signed-rank test to compare the 2 sets (pre and post test scores). However, these results should be interpreted with caution given our small sample size. We used the Wilcoxon signed-rank test since it is most robust with small sample sizes than other parametric analyses. However, we recognize that small sample sizes may reduce our capacity to detect meaningful relationships within our data and, at the same time, limit the generalizability of our results.

Qualitative

We used a deductive thematic approach where we already had a predefined thematic framework from McNeal et al. (2017) and Monroe et al. (2019), and aimed to validate these theories. We added questions about teacher collaboration and thoughts about participating in citizen science, which align with McNeal's (2017) motivations to teach climate change. We also included questions about engagement and relevance, which are the main focuses related to Monroe's (2019) strategies for success while learning about climate change. These, as well as other questions, allowed us not only to corroborate both McNeal's (2017) and Monroe's (2019) theories but also to create a comprehensive list of strengths and challenges in the program (see the second research question, *"What are the challenges and best practices associated with implementing citizen science programs within the K-12 educational system in Miami?"*) and to understand if a citizen science program is a good way of engaging teachers in climate change education (see the third research question, *"Can a citizen science program motivate teachers to learn about climate change?"*

RESULTS AND DISCUSSION

This section is organized into two sections: "Citizen science's impact on teachers' knowledge" and "Citizen science best practices and challenges." In the first section, we provide insights into the fall teacher training workshop. We discuss the teachers' content learning from the training workshop, which helped us answer our first research question: *How does participation in a citizen science program impact teacher knowledge about plant physiology/ climate change in the context of Miami?* In the second section, we examine the strengths and challenges faced during the program. This section helped us answer our second research question: *What are the challenges and best practices associated with* *implementing citizen science programs within the K–12 educational system in Miami?* The positive outcomes of the workshop and the entire program, as well as their potential implications for teacher motivation are highlighted in both sections. This helped us to address our third question: *Can a citizen science program motivate teachers to learn about climate change?* We also discuss the potential contribution of our experiences to creating effective guidelines for citizen science projects and workshops.

CITIZEN SCIENCE'S IMPACT ON TEACHERS' KNOWLEDGE

Fall teacher training workshop (from questionnaires)

Our teacher training workshop was held annually in the fall and was found to be one of the main strengths of this project. Teachers were required to attend this workshop to participate in this project. Additional workshops were offered on a case-by-case basis if teachers were unable to attend the first workshop. Teachers are encouraged to participate in as many challenges as they can to accrue points and win prizes at the end of the year. We have had high participation numbers during our fall workshop each year (Year 1 = 61, Year 2 = 21, and Year 3 = 48 teachers from elementary schools and 28 from middle schools). However, not all the teachers answered our questionnaire, and we are presenting here only the results gathered in the surveys. Most of the teachers that have participated in our teacher training workshop are from public schools, and as expected, most of them teach in areas classified as science (Supplemental File 5: Participants background). However, an interesting result is that teachers from other areas (e.g., family and consumer sciences and intensive reading) attended the workshop. The Shade our Schools—Leaves are Cool! project does include elements of writing and arts, which may attract these teachers to participate. We have planned the workshops under the assumption that teachers from different areas may be interested in citizen science programs. In addition, we also show that most of the participating teachers have several years of experience. This may be due to the challenges that early-career teachers face, which may prevent them from participating in voluntary programs like this one.

Evaluation of teacher training workshop (post questionnaire)

In general, each year, teachers reported that the training workshop met their expectations and gave good reviews in all areas (Supplemental File 11: Workshop evaluation). If teachers left the workshop thinking that the information they learned was useful and was presented in a clear manner, and also were willing to come back to a similar event, that may indicate that they feel more confident about the content. If they increased their comfort for teaching this subject, that may be linked to a deeper instruction (National Research Council 2007).

Most of the teachers in Years 1 and 3 expressed that the most helpful part of the workshop was the hands-on experiences, with answers like:

- "Learning from the UM research scientists and going outside to practice doing the actual challenge."
- "The most helpful part was when everyone went outside to see the data collection first hand."
- "Being able to do the experiment myself."

To observe COVID-19 safety measures during Year 2, we carried out the fall training workshop fully online. Protocols were demonstrated using a previously recorded video and images. In this case, teachers found that providing a video with the protocols was very useful, with answers like:

- "The presentation of the workshop was very informative, but the video that explained the experiment was very helpful."

Content learning from teacher training workshop (pre and post questionnaire)

During Year 2, seven out of nine content questions showed an improvement in their mean score (Supplemental File 12: Pre and post questionnaire scores Year 2 workshop). During Year 3, four out of six questions showed an increase in the mean score (Supplemental File 13: Pre and post questionnaire scores Year 3 workshop). The interrater reliability was over 70% for all questions but one. In addition, total scores for individual teachers significantly increased for the post questionnaires in Years 2 and 3 (Supplemental File 14: Wilcoxon Signed-Rank Test), with a few challenging questions. This is an extremely complex topic that will have to be better explained in future editions of the workshop. During our third year, open-ended questions like what is climate change, the greenhouse effect, or thermoregulation in plants did not show an improvement between pre/post questionnaires. We believe that teachers were rushing by the end of the workshop and answered the post questionnaire very quickly. Teachers took an average of 729.2s to answer the pre questionnaire with 13 questions, while they took an average of 369.4s to answer 19 questions from the post questionnaire. We recommend that in the future, teachers take the survey in their own time within one week of the workshop.

In Year 3, we asked whether teachers had prior participation in the program, and a subset of teachers responded affirmatively. The analysis of their pre-questionnaire mean scores showed a higher value, although it did not reach statistical significance according to the Mann-Whitney U Test ($p = 0.1$), when compared with scores of other teachers who had not participated before. This observation aligns with Liu et al.'s (2015) findings, which highlight that teachers might continue to face challenges in grasping climate change concepts even after receiving professional training. Based on these insights, we propose that extending the program could yield additional benefits for these experienced teachers.

The positive outcomes of our workshop enabled us to effectively tackle the "expectancies of success" and the "cost-value" components of McNeal et al.'s (2017) framework. By equipping teachers with the confidence to discuss the subject and implement enhanced instructional practices, we successfully boosted student motivation.

CITIZEN SCIENCE BEST PRACTICES AND CHALLENGES

Strengths

One of the main strengths of the program is our annual teacher training workshop. During this workshop, teachers get the chance to learn about climate change and practice data collection.

Another strength is participation from teachers across different subject areas (science, art, language, etc.), which is critical because several schools conduct the study as an interdisciplinary project that summarizes and analyzes results within an artistically displayed journal. In the end-of-the-year questionnaire (Year 3), we asked the teachers: "Did you collaborate with teachers of other areas to complete the challenge?" and 26 out of 40 participants responded positively (12/18 in elementary school preK–2, 8/11 in elementary school 3–5 and 6/11 in middle school). Teachers learn very effectively from other teachers (McNeal, 2017), and our data suggests that this may be a strength of the program, since most of the teachers collaborated. This touches on the "expectancies of success" and the "cost-value" aspects of McNeal et al.'s (2017) framework, as we have prepared teachers to speak confidently about the subject and implement improved instructional practices that enhance student motivation.

Also, the inclusion of state benchmarks in the challenge helps teachers to adapt the program to their curriculum. This helps with the most important barrier to teach about climate, which is that it usually does not fit in teachers' curriculum (Wise 2010). Furthermore, the interaction with the scientists at UM who are working on Shade our School—Leaves are Cool! seems to be beneficial for both teachers and students. This is in accordance with McNeal et al.'s (2017) framework on teachers' motivations regarding "utility value" because we provided state benchmarks they can use to accommodate the study in their curriculum.

Teachers also indicated that the project was a fun and engaging for their students; thus, we were able to verify one of Monroe et al.'s (2019) strategies to ensure success in climate change education: "intervention should engage the participants." When Fairchild staff asked teachers about their favorite challenge during the first year, some replied with answers such as:

- "Shade Our Schools. We had fun never having measuring the temperature of leaves!"
- "My favorite was Shade our Schools. I thought it was thrilling to be a part of a real research project. The students felt vital to a real study"
- "Shade our school. Because I love to plant trees and teach about its importance in our planet."
- "We worked with the leaves. The students enjoyed working with thermometer and drawing the leaves. The enjoyed counting the boxes to get the area of the leaf. Learned a lot and had fun."

Monroe et al. (2019) also described how the experience should be relevant to the learners and relate to their lives. The way the program was created, incorporating native species and using Miami as context, along with answers such as the following, ensured that our strategies align with Monroe's views. Students learned about how climate change is impacting Miami, the city where they live, so they could connect what they learned to their context:

- "To connect what they are learning in the classroom to real life situations, and help them see how science can apply to their everyday lives."

At the annual Teachers' Forum Workshop (a meeting that we held each year at the end of the program to get feedback), end-of-the-year questionnaires revealed that most of the teachers are interested in the FC program to increase their students' interests in science and plants. All the teachers surveyed during Year 3 responded "yes" to the question: "Do you think your students learned with the project?" The following are a representative sample of survey comments during all 3 years:

- "Citizen science projects give our students hands on experiences with scientific methodologies actually used by scientists."
- "Students tend to have a limited view of the importance of plants. Exposing them to exciting projects that can affect their lives tend to make it more personal, and elicit more interest."
- "Citizen science is the most valuable science learning for students."

- "Lack of activities at my school – I need ways to enrich."
- "Students loved everything: taking the leaf temperature & measuring & illustrating them."

Some teachers mention that student's experience a sensation of being "authentic scientists" while engaged in the process of collecting and analyzing data for ongoing research. This is similar to what Perron (2021) described, where educators state that they have engaged their students in this citizen science initiative to provide them with the opportunity to engage in real-life scientific practices. These activities not only facilitate learning for both students and teachers regarding concepts like climate change, but also cultivate a sense of ownership and curiosity toward the subject. This can lead to the development of a more profound understanding of scientific exploration and a heightened motivation to engage with intricate topics. These are some examples of these answers:

- "Extremely interesting, I really enjoyed the field research and so the kids and I quote 'Miss, I feel like a real scientist.'"
- "I love teaching about climate change and allowing students to feel like real scientists. Students like knowing they are real scientists contributing to real research to save the world."
- "It was amazing to know that their research mattered. They [students] were real scientists."

The end-of-the-year survey (Year 3) revealed that most teachers think that participation in the challenge actually improved their instruction in the field of climate change and plant physiology (11/14 in elementary school preK–2, 9/11 in elementary school 3–5 and, 13/14 in middle school). In addition, most of them think that participating in ongoing current research is a good idea (14/14 in elementary school preK–2, 13/13 in elementary school 3–5, and 10/11 in middle school).

However, a couple of teachers mentioned their own desire or need to participate in the program and how it can directly benefit them. This aligns with the "teaching philosophy of teachers" (McNeal et al. 2017), as we emphasized their role as both scientists and educators. Here are some relevant examples of their answers:

- "It's my dream as a science lover and a hands on science teacher."
- "Obviously from the answers to the quiz I need to learn more about this topic."

We successfully addressed four of the five aspects described by McNeal et al. (2017) to increase teachers' motivation: (1) expectancies of success, because in our workshops we prepared teachers to talk about the subject; (2) teaching philosophy, because we emphasized their role as scientists; and (4) utility value, because we provided state benchmarks they can use to accommodate the study in their curriculum; and (5) "cost-value aspect," as well-prepared teachers can offer improved instructional practices that enhance student motivation. According to Monroe et al. (2019) there are two strategies to ensure success in climate change education: (1) The information should be personally relevant to learners, and (2) intervention should engage them. Because the teachers involved in the project are conducting a local study, usually analyzing native endemic plant species and debating about the threats of climate change for Miami, we have also addressed these points. Based on the answers to our end-of-the-year questionnaires, teachers and students find our study exciting and engaging.

Challenges

One of the focal questions of our research pertains to the examination of barriers and strengths associated with the participation of teachers and students in citizen science programs. The end-of-the-year questionnaires from Year 1 identified some challenges related to the participation in our program. This list was compiled from teachers who expressed that the Shade our Schools—Leaves are Cool! project was their least favorite, and from the question regarding barriers found while doing this challenge. We identified challenges related to resources and preparation that highlighted the importance of access to equipment and training. Some examples are:

- Insufficient access to equipment.
- Protocols were confusing to some teachers, especially those that did not participate in our workshop.
- Plant identification.
- Teacher did not have enough background to perform it.

We also identified the need to take into account the importance of having age-appropriate activities that match students' development.

- Some schools were preK–1st grade, and teachers stated the challenge was too complex for their students' age

There were logistical challenges, as well:

- Time constraints.
- Lack of trees in some schools.
- ESE (exceptional student education) students.

Working with exceptional student education students require additional considerations and adaptations.

All these issues were addressed in Year 2 by:

- reducing the amount of materials needed for the completion of our protocol;
- providing a detailed video with all the steps of our protocol (English and Spanish);
- designing experiments that could be done at home, parks, etc.;
- directing the challenge toward middle school students; and
- allowing for at-home experiments if there is not enough time in school.

During Year 3 we identified further logistical and preparation challenges such as:

- Teachers do not like trainings on Saturday.
- Teachers would like us to train students directly.
- Due dates cannot be close to state testing dates because teachers do not want to lose instructional time during that period.
- Mandatory workshops should provide master plan points required for teacher certification renewal in Miami-Dade County Public Schools.
- The challenge works better with small groups.

We expect these points are taken into consideration when creating other initiatives like ours. Our experiences can contribute to create effective guidelines for citizen science projects and workshops that will not only generate real data, but can also train students and teachers in crucial subjects like climate change.

CONCLUSIONS

Climate change education is becoming increasingly important, especially for the people in Miami since the city "faces the largest risk of any major coastal city in the world," a consequence of climate change. (Raimi et al. 2020, page 21). However, this subject is not systematically established in Florida's educational programs, and teachers' understanding of the topic is limited, often overlooking how the evidence in this field is developed. One of the most effective ways to engage teachers in learning about climate change is to get them involved in authentic research. In this case, their role as scientists is emphasized and an increase in knowledge about this topic can give them the confidence and motivation to improve instruction. We believe we are able to create a shift in the educational practices of teachers participating in the Shade our Schools—Leaves are Cool! citizen science project through The Fairchild Challenge program. The goal of this project is not only to collect data for ongoing research for UM scientists, but also to provide an opportunity for teachers to enhance their content knowledge in the areas of plant physiology and climate change.

Our results revealed that our fall teacher training workshops increased teachers' knowledge in the topics previously described. We also provided a wide variety of resources that include educational videos (some bilingual), power points, articles, and constant communication between teacher and scientist that enrich the experience. More prepared teachers will be able to provide better instruction, leading to a positive impact on student achievements. In addition, teachers' participation during data collection and analysis increased their engagement and motivation to teach the subject. Therefore, our intervention of the Shade our Schools—Leaves are Cool! project can effectively increase students' success in learning about climate change.

We acknowledge that our sample size is limited for the statistical analyzes presented, which may have affected the reports presented here. Although our results are consistent with our expectations, we have to note that we relied on self-report, and participating teachers were a self-selected group that may not be an accurate representation of a larger teacher population.

DATA ACCESSIBILITY STATEMENT

Data is available upon request.

SUPPLEMENTARY FILES

The supplementary files for this article can be found as follows:

- **Supplemental File 1:** Florida State Academic Educational Standards included in the *Shade our Schools - Leaves are Cool!* challenge for Elementary and Middle Schools. State benchmarks can be found on https://www.cpalms.org/. DOI: https://doi.org/10.5334/cstp.619.s1
- **Supplemental File 2:** *Shade our Schools – Leaves are Cool!* Citizen Science Project goals by academic year. DOI: https://doi.org/10.5334/cstp.619.s2
- **Supplemental File 3:** Information collected and number of questionnaire respondents. DOI: https://doi.org/10.5334/cstp.619.s3

- **Supplemental File 4:** Number of teachers who participated in the workshop and the entire Citizen Science program. DOI: https://doi.org/10.5334/cstp.619.s4
- **Supplemental File 5:** Participation in Teacher Training Workshop questionnaire*. DOI: https://doi.org/10.5334/cstp.619.s5
- **Supplemental File 6:** Participation and data collection in the *Shade our Schools – Leaves are Cool!* Citizen Science Program. DOI: https://doi.org/10.5334/cstp.619.s6
- **Supplemental File 7:** Teacher Training Workshop post questionnaire (Year 1: 2019–2020). DOI: https://doi.org/10.5334/cstp.619.s7
- **Supplemental File 8:** Teacher Training Workshop pre and post questionnaire (Year 2: 2020–2021). DOI: https://doi.org/10.5334/cstp.619.s8
- **Supplemental File 9:** Teacher Training Workshop pre and post questionnaire (Year 3: 2021–2022). DOI: https://doi.org/10.5334/cstp.619.s9
- **Supplemental File 10:** End of the year questionnaires at Teachers Forum (years 1–3: 2019–2020, 2020–2021 and 2021–2022). DOI: https://doi.org/10.5334/cstp.619.s10
- **Supplemental File 11:** Teachers' evaluations of the *Shade our Schools – Leaves are Cool!* Training workshop. DOI: https://doi.org/10.5334/cstp.619.s11
- **Supplemental File 12:** Average scores and standard deviation per item in Pre and Post questionnaires for Year 2 workshop. DOI: https://doi.org/10.5334/cstp.619.s12
- **Supplemental File 13:** Average scores and standard deviation per item in Pre and Post questionnaires for Year 3 workshop. DOI: https://doi.org/10.5334/cstp.619.s13
- **Supplemental File 14:** Mean total scores for Pre and Post test and one-tailed Wilcoxon Signed-Rank Test. DOI: https://doi.org/10.5334/cstp.619.s14

ETHICS AND CONSENT

The IRB at UM determined this study meets the criteria for an exemption as described in Federal Regulation 45 CFR 46.104.

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COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

Olga Tserej guided the conception, design, data collection, and analysis of this study, and wrote this manuscript. Dr. Brian Sidoti contributed to the design, data collection, and analysis of this study, and contributed to the writing of this manuscript. Stacy Assael contributed to the conception, design, and data collection of this study. Amy Padolf contributed to the conception and design of this study. Monica Bistrain contributed to the data analysis of this study. Dr. Kenneth Feeley and Dr. Ji Shen contributed equally to the conception and design of this study and to the writing of this manuscript.

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