Citizen Science in the Classroom: Data Quality and Student Engagement

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Abstract

This project sought to evaluate a citizen science project in the classroom via two foci: 1) whether the project could benefit students by increasing their science engagement, and 2) whether students could generate high-quality data. A total of 116 students in two honors biology and four environmental studies classes at a rural high school in the Chesapeake Bay watershed gathered water-quality data from a local stream. Water-quality data gathered from the same area by professionals were obtained from the local water treatment company via email. The quality of the student data was determined by comparing student data to professional data, as well as by eliciting students' understanding of data quality before and after the project via short-answer questions. Students' emotional and behavioral engagement were measured and compared before and after the project using a Likert-type questionnaire, and their behavioral engagement was additionally quantified via observation. The results showed that student data gathered using high-quality instruments were similar to professional data, according to unpaired *t*-tests. Students' self-reported engagement did not change, but the students' observed behavioral engagement was significantly higher post-intervention. The similarity between student and professional data and the increase in students' behavioral-science engagement show that citizen science has the potential to benefit both students and scientists at the same time, by providing a high-quality dataset while increasing student engagement. This project has implications for formal and informal science education providers, and those interested in developing citizen science programs for youth and adults.

Citizen science projects have proliferated over the last decade, as has research on the process and benefits of citizen science (Hovis et al., 2021). At the same time, the goal of getting and keeping students engaged in science has been consistent in science education literature, even as the exact definition of student engagement has developed over time (Kennedy & Odell, 2014; Sinatra et al., 2015). The process of citizen science has potential benefits for the scientists who use the data, as well as the citizens who engage in its collection: scientists may gain large, useful datasets, and both adult and youth participants may gain interest, knowledge, and/or skill in science, as will be laid out in more detail later in this introduction. Although adults appear to make up the majority of citizen-science participants (Jones et al., 2018), youth participation in citizen science is also present in the research. Past research has been done on youth and young-adult educational outcomes as the result of citizen science (e.g., Vitone et al., 2016) and on the quality of data collected by youth citizen-science participants (e.g., Castagneyrol et al., 2020), but few studies consider data quality alongside educational outcomes, such as science engagement. Also, as will be discussed, there are various factors that can affect whether a citizen science project is beneficial for both participants and the scientists hoping to use the resulting data (Conrad & Hilchey, 2011; Nicholson et. al, 2002).

The purpose of this study was to consider how a citizen science project in a classroom setting could be beneficial to scientists and students by examining the quality of the student-collected data produced by the project and impacts on student participants' science engagement. The school where the study took place is a high school in a rural part of the Chesapeake Bay watershed. Past students at the school had done lessons involving water-quality tests of a local stream that runs through school property, as part of larger ecology units. The research team and the science teacher who designed the stream-testing project saw an opportunity to integrate teaching and research in the form of a larger citizen science project that would allow the student data to potentially be uploaded to FieldScope.org (Biological Sciences Curriculum Study, 2018), a citizen science database with a collection of water-quality data across the Chesapeake Bay watershed. In the following sections, we will use past literature to define both data quality and student science engagement for the purposes of this study.

Citizen Science, Science Education, and Data Quality

Citizen science is a process during which professional scientists recruit non-scientist volunteers to do science alongside them (Bonney et al., 2014; Hovis et al., 2021). The characteristics of the volunteers engaged in a citizen science project vary greatly between, and sometimes within, the projects in question. They may or may not be trained (Bonney et al., 2014; Kountoupes & Oberhauser, 2008; Sheppard & Terveen, 2011); they can be adult or youth participants (Bonney et al., 2014; Widder et al., 2014; Zoellick et al., 2012); and the youth participants may do projects in an informal science education (ISE) or a formal science education (FSE) setting (Bonney et al., 2014; Zoellick et al., 2012).

Though participants in citizen science projects vary—in level of training, age, and other demographics—what they have in common is that they are volunteers; none are paid for their data collection or analyses. They do, however, have the potential to benefit from a citizen science project in other ways. Participants in citizen science have been found to learn from their participation, both content knowledge (e.g., facts about birds) (Brossard et al., 2005; Evans et al., 2005; Haywood, 2016; Parrish et al., 2019), and/or knowledge of the scientific process (Cronin & Messemer, 2013; Hovis et al., 2021). Long-term participation in a citizen science project can affect adults' identity, particularly their concept of themselves as scientists, as well as their self-worth (He et al., 2019). In addition, environmentally focused citizen science projects have proliferated over the last several years (Dickinson et al., 2012; Hovis et al., 2021), and these types of projects have been shown to positively affect participants' relationships with their own small piece of the environment (e.g., their backyards) by making them feel more connected to or more aware of that personal environment (Evans et al., 2005; Haywood, 2016). Sometimes, participants' relationships with the environment remain unchanged before and after a citizen science project; however, when this is the case, that lack of change is likely because their concern for the environment is the reason they volunteered in the first place (Brossard et al., 2005). Student participants in citizen science in both ISE and FSE contexts have been found to benefit similarly to adults in that they may gain content and/or process knowledge or may gain interest in science or their environment (Bonney et al., 2014; Cardamone & Lobel, 2016; Widder et al., 2014); there is little research considering whether students may gain content knowledge, process knowledge, and interest all from the same project.

The 'doing science' aspect of citizen science can also happen in several ways, including data analysis as well as various types of data collection (Hovis et al., 2021; Jones et al., 2018; Tinati et al., 2015). The main reason that data-collection citizen science is useful for professional scientists is that it allows for large amounts of data to be gathered in a relatively small period of time and over a large geographic area in a way that they would not be able to do on their own (Zoellick et al., 2012). It also allows scientists to gain access to residential land, or land that would otherwise not be available for sampling (Cooper et al., 2007). And—although not the focus of this study—citizen science can also be used to analyze very large datasets, which professional scientists would not be able to process in a timely manner (Bonney et al., 2014; Tinati et al., 2015).

Citizen science data collection is not without its challenges. Volunteers used for data collection in citizen science projects are not always heavily trained, if they are trained at all (Bonney et al., 2014; Kountoupes & Oberhauser, 2008; Sheppard & Terveen, 2011). This raises concerns within the scientific community as to whether the data collected by volunteers are of high quality, and therefore whether the data are valid to be published in peer-reviewed papers. Studies have found different results when looking at the quality of data collected by volunteers. For the most part, researchers who claim to be evaluating data quality do so by comparing data collected by volunteers to a reference set of data collected by trained professionals (Aceves-Bueno et al., 2017; Castagneyrol et al., 2020; Nicholson et al., 2002; Parrish et al., 2019). In a quantitative review of several papers on citizen science, Aceves-Bueno and colleagues (2017) found that only somewhere between 51% and 62% of citizen science data were statistically similar to professional data, depending on the comparison method. Other reviews have found that it is possible for volunteers to collect quality data, defined again as data similar to data collected by professional scientists, except when the professionals have equipment that is more precise or easier to use (Nicholson et al., 2002). Reviews have also found that data quality varies between projects when groups are not trained enough, and/or not enough thought is put into factors like sample size and consistency (Conrad & Hilchey, 2011). A look at individual studies shows similar variation as reported in reviews: Cronin and Messemer (2013) found that adults participating in a citizen science program designed to have a strong educational component were able to collect a large dataset with good internal validity, while Castagneyrol and colleagues (2020) found that school students participating in a citizen science project on insect predation overestimated the predation in comparison to trained professional scientists, but not in comparison to professional scientists whose area of expertise was outside the project in question. Parrish et al. (2019) found that adults participating in a seabird-identifying citizen science project were likely to become more accurate in their predictions as their experience in the program continued.

Although data quality is often operationalized as similarity to professionally collected data, not all authors use the same measure. While Aceves-Bueno and colleagues (2017) found that only 51–62% of citizen-collected data were statistically similar to professionally collected data, they also found that, in the same papers, researchers described the quality of data collected by citizens positively 73% of the time. Sheppard and Terveen (2011) looked at one citizen science program involving 35 high schools and found that they were well able to balance the goals of data quality and education, and that students and teachers were all aware of the value of consistency and careful sampling, but drew these conclusions entirely through interviews, without comparing the high schoolers' data to any other dataset.

Conceptual Framework: Student Engagement in Science Education

Research on citizen science often overlaps with research on the field of public engagement with science (PES). PES has been written about as both a practice and a goal; it tends to encompass non-scientist citizens doing things such as participating in informal science education projects, gaining interest in science relevant to themselves, and having scientific dialogues with other citizens or with professional scientists (McCallie et al., 2009; Stilgoe et al., 2014). In education research, the term 'engagement' is generally used to mean, not public engagement *with* science, but student engagement *in* science; however, the similarity between the terms is not coincidental. Increasing aspects of student engagement in science likely enhances their future public engagement with science (Lin et al., 2012).

The specific definition of student engagement has varied in the years it has been studied (Appleton et al., 2008; Fredricks et al., 2016; Sinatra et al., 2015). Over time, past theorists have divided engagement in school into anywhere from two to four dimensions: behavioral and emotional/affective (Appleton et al., 2008; Marks, 2000); behavioral, emotional, and cognitive (Fredricks et al., 2004); behavioral, emotional, cognitive and agentic (Sinatra et al., 2015); or some combination of the above with the addition of a social dimension (Fredricks et al., 2016). There is some overlap in the definitions of the dimensions of engagement, especially when considering how they may be operationalized and measured (Sinatra et al., 2015). For the purposes of this study, we focus on behavioral and emotional engagement as external and internal markers of student engagement in a subject.

Behavioral engagement is evident in student behavior; it includes such actions as class participation, putting effort into assignments, and speaking positively about a class or subject (Fredricks et al., 2004; Fredricks et al., 2016; Sinatra et al., 2015). Affective, or emotional, engagement has to do with students' interest in a class, and their feelings of belonging (Fredricks et al., 2004; Fredricks et al., 2016; Sinatra et al., 2015). Student engagement has been causally linked to achievement in multiple subjects (Appleton et al., 2008; Finn, 1993; Newmann, 1992; Sinatra et al., 2015): increased science engagement leads to increased science achievement (Fredricks et al., 2016; Grabau & Ma, 2017). Lin et al. (2012) also found that interest and emotion (i.e., the affective aspects of engagement) as well as interaction with science outside of school settings (i.e., one aspect of behavioral engagement) correlate positively with scientific literacy. Increased science engagement in school, Lin et al. (2012) suggest, can lead eventually to more scientifically literate adults.

Because of these impacts of increased engagement, various studies have considered how to increase student engagement in science. Aspects of science engagement, including student interest in science topics and interaction with the material, have been increased in the past through activities that are at once challenging and frame students as experts in the discipline (Olitsky, 2007). Another way that student interest has been increased is via relevance interventions, encouraging students to connect what they learn in the classroom to their own lives (Hulleman & Harackiewicz, 2009). One study of undergraduate students found that their interest in science and interest in participating in science (two different variables) increased as the result of a citizen science project in the classroom (Vitone et al., 2016). Citizen science is a potential way to challenge grade-school students, frame them as experts, and provide an activity with relevance to students' lives, thereby increasing students' science engagement and leading to scientifically literate adults.

Research Questions

During this study, we sought to determine whether a citizen science project in a high school classroom can be beneficial to both scientists and students. Specifically, we designed two research questions, referred to in the following sections as question one (RQ1) and question two (RQ2). We further broke down RQ1 into two parts: RQ1a focused on the comparison between the student and professional data quality, drawing from past research on citizen science data quality (Aceves-Bueno et al., 2017; Castagneyrol et al., 2020; Nicholson et al., 2002; Parrish et al., 2019), while RQ1b focused on how students express their understanding of data quality. We recognized that students' ability to collect quality data may be impacted by anything ranging from their equipment to their understanding of data quality, and wanted to ascertain whether students could understand the goal of collecting quality data even if other circumstances in this case study prevented their data from being similar to professional data. Our research questions for the study were:

> **RQ1**: In what ways, if any, can high school students be said to collect high-quality data from a local stream?
>
> > **RQ1a**: How do student-collected data compare statistically with data collected by professionals?
> >
> > **RQ1b**: How do students express an understanding of data quality and how to assure it?
>
> **RQ2**: In what ways, if any, does student engagement in the science classroom differ before and after students gather stream-characteristic data from a local stream?

Methods

This research project was a mixed methods study, which took place in a rural Mid-Atlantic high school during the spring semester of the 2017–2018 school year. Mixed methods were chosen because of the aforementioned variety of ways to operationalize 'data quality.' The school where the study took place is one of three public high schools in the county and has a reputation for being the most rural, surrounded by various natural resources for students' learning.

The school and classes were chosen because the first author was serving as an instructor in the school at the time. As a master's student at the time, the first author was seeking opportunities for a research project. Another instructor at the school who was mentoring the first author had used lessons on water quality in her environmental science classes in the past and offered these lesson plans to the first author to adapt and use in this research. The lessons involved testing water from a local stream that runs through school property, behind and downhill from the building.

An additional impetus for testing the water quality of this stream was that teachers and students at the school had noticed the bank of the stream was eroding at an alarming rate. Teachers noted that two makeshift bridges that were across the stream in spring of 2016 were carried into the streambed by flooding by the fall of 2017. As part of the lessons leading to this research project, students walked around the school grounds and noted ditches formed by stormwater runoff, and wondered if poor stormwater management played a role in the stream erosion. The teacher who originally wrote the water-quality lessons was a particularly outspoken advocate for the stream and considered that any published research on the lessons would be a positive contribution to the community and environment.

Research Participants

The research took place in six high school classes: two honors biology classes, comprising 49 students, and four environmental science classes, comprising 116 students. All but three of the honors biology students were ninth graders, and 67% of them were female. The environmental science classes had students from every grade in the school (ninth through twelfth), though a majority were eleventh or twelfth graders; a small majority of them (54%) were male. Almost all of the student participants were White and did not identify as Hispanic, which is representative of the racial/ethnic diversity of the school as a whole.

The university's Institutional Review Board approved all study procedures, as did the Institutional Review Board of the public school system where the research took place. All of the high school students participating in the research were required to assent and receive parental consent to participate in the study. The students who received consent and gave assent completed pre- and post-surveys before and after the citizen science intervention and were observed before and after the intervention.

Intervention

The citizen science intervention took place over four non-consecutive class periods, broken up by a weekend and a day of standardized testing, during lessons that align with the Next Generation Science Standards (NGSS Lead States, 2013). The lessons took place about halfway through the spring semester of the school year, meaning that students had already experienced slightly over six months of instruction in their classes (biology or environmental science). In the biology classes, units earlier in the year included Science and Engineering Practices, Living Systems, Chemistry of Living Systems, Matter and Energy in Living Systems, Ecosystems: Stability and Change, Cells: Stability and Change, and Structure and Function of DNA. In the environmental science classes, units earlier in the year included Nature of Environmental Science, Solving Environmental Problems, Ecosystems and Energy, Ecosystems and Organisms, Matter Cycles, and Weather Patterns. Information about the Chesapeake Bay was integrated throughout the course.

For the intervention, each class first had a lesson explicitly focusing on background information about the Chesapeake Bay and the students' connection to the Chesapeake Bay watershed, as well as instruction on ensuring data quality. The next sequence of lessons had the students practice water-quality tests on tap water, take observations of the local stream that runs behind the school, and do the same water-quality tests on water taken from the stream. The students were reminded multiple times during the lesson sequence that their water-quality data would be used beyond their classroom in the first author's research, and potentially uploaded to FieldScope.org, a website with an ongoing project on Chesapeake Bay watershed data (Biological Sciences Curriculum Study, 2018).

Data Collection

RQ1a: Data Comparison Between Students and Professionals. We sought to determine whether students would be able to collect quality data during a citizen science project. We emulated other authors in partially operationalizing high-quality data as data similar to that collected by professionals (Aceves-Bueno et al., 2017; Castagneyrol et al., 2020; Nicholson et al., 2002; Parrish et al., 2019). The stream surveyed during the citizen science intervention runs through school property, and there is also a wastewater treatment plant on school property, but run by the local water commission. At the beginning of March 2018, the students collected water-quality data from a part of the stream downstream of the wastewater treatment plant; the students tested the temperature, conductivity, nitrates, turbidity, dissolved oxygen, and pH of the water. Professionals from the local water commission tested the effluent from that plant; the first author was able to obtain their data from the month of February for comparison with student data. Professionals recorded the biological oxygen demand, total suspended solids, ammonia, dissolved oxygen, and pH of the water. Because the only variables in common were dissolved oxygen and pH, these were the variables we compared.

RQ1b: Student Understanding of Data Quality. We recognized that students may be *able* to collect data similar to professional data, but may be kept from doing so by a variety of factors, such as equipment quality (Nicholson et al., 2002). To determine student understanding of data quality, we also included two open-ended questions in both the pre- and post-intervention surveys, asking students to define data quality in their own words, and to explain how best to assure quality data when performing any science experiment.

RQ2: Student Science Engagement. We also sought to determine whether a citizen science project would impact student engagement in science. In order to quantify student engagement, we used a version of the Engagement versus Disaffection with Learning student self-report questionnaire (Skinner et al., 2009), adapted to measure student engagement in the selected science classes. This questionnaire quantifies both the behavioral and emotional aspects of engagement, and is appropriate for assessing engagement in a specific class, rather than in school in general, and can be used with elementary, middle, and high school students (Fredricks et al., 2011). The questionnaire consists of 25 statements designed to measure either a students' engagement (positively coded) or disaffection (negatively coded) within a class. Students record their agreement with each item on a four-point Likert-type scale, from 1 (strongly agree) to 4 (strongly disagree). Example items include "When I'm in my Biology class, I listen very carefully" (behavioral engagement), and, "When we work on something in Environmental Studies, I feel discouraged" (emotional disaffection). The Cronbach's alpha scores for the behavioral engagement (10 items) and emotional engagement (15 items) subscales, calculated separately pre- and post-intervention, range from 0.81 to 0.87.

In an additional quantification of behavioral engagement, the Student Record of Behavior (StRoBe; Marchant, 1989) was used to measure students' behavioral engagement through pre- and post-intervention observation. The first author chose a day before and after the intervention when she observed every student during a note-taking activity. To do this, she looked at one student and followed the steps of the StRoBe to code them as either Verbal (V) or Behavioral (B), Appropriate (A), Inappropriate (I), or Undecided (U); i.e., a silent, on-task student would be coded BA. She then moved on to the next student in the row, recorded a code for them, and continued. After coding the last student in the room, she looked again at the first student, and continued this until she had twelve observations for each student.

A summary of the data sources used can be found in Table 1.

Data Analysis

In order to answer RQ1a and determine the quality of the student data, we compared the student and professional pH and dissolved oxygen data using *F*-tests for equality of variance, and unpaired *t*-tests to compare the means. The *t*-tests were two-tailed, with an alpha level of 0.05. To answer RQ1b, we qualitatively analyzed students' answers to the short-answer questions before and after the intervention using a content analysis. The first author first read through the student responses and found emerging themes in response to each question, as described in Cresswell (2012); she then re-read the responses and coded each short response as aligning with one or more themes. The second author then reviewed the first author's coding independently, and we discussed any difference of opinion until we reached consensus.

To answer RQ2, we compared students' engagement before and after the intervention by comparing students' pre- and post-intervention responses to the modified Engagement vs. Disaffection with Learning questionnaire using paired *t*-tests. The *t*-tests were again two-tailed, with an alpha level of 0.05. We tested the normality of the data and deemed it appropriate to meet the assumptions of a *t*-test. Although the data resulting from the Likert-type questionnaire are ordinal rather than continuous, parametric vs. non-parametric tests have been found to have equivalent power when comparing Likert-type responses, particularly when the datasets are similar in size (de Winter & Dodou, 2010). To further compare the students' behavioral engagement before and after the intervention, we compared the first author's counts of students' total appropriate behaviors (either BA or VA) pre- and post-intervention, and the total number of inappropriate behaviors (either BI or VI) pre- and post-intervention using paired *t*-tests.

Results

RQ1a: Data Comparison Between Students and Professionals

One purpose of this research project was to determine whether students would be capable of collecting high-quality data (i.e., data that could be used by professional scientists) during a citizen science project. Although both students and professionals associated with the wastewater treatment plant collected various kinds of water quality data, the only variables collected by both groups were dissolved oxygen and pH. Working

Table 1. Data Sources Used to Answer Research Questions 1 and 2

Research Question	Data Source 1	Data Source 2
RQ1: Data quality	RQ1a: Student and local water commission water-quality data	RQ1b: Open-ended questions about data quality on pre and post survey
RQ2: Student engagement	Pre and post student self-report Likert-type questionnaire	Pre and post teacher behavioral observations: StRoBe

in groups, students collected dissolved oxygen data using a chemical test, and pH data using both a chemical test and probeware. According to the facility superintendent of the wastewater treatment plant, professionals collected pH and dissolved oxygen data using probeware. We tested the normality of the data and deemed it appropriate for parametric tests. We compared the student data to professional data using *F*-tests for equality of variance. The dissolved oxygen data were heteroscedastic, while the pH data were homoscedastic; the results of the *F*-tests are in Table 2. Because the dissolved oxygen data were heteroscedastic, we used a Welch's unpaired *t*-test to compare the student and professional dissolved oxygen, because this test does not require equality of variances. We used unpaired *t*-tests which require homoscedasticity to compare the student and professional pH. The student dissolved oxygen data (M = 10, SD = 4) were not significantly different from the professional dissolved oxygen data (M = 9.5, SD = 0.6), $t(34) = 1.17$, $p = 0.25$. The student pH data gathered using a chemical test (M = 6.9, SD = 0.4) were significantly different from the professional pH data (M = 7.6, SD = 0.3), $t(35) = -3.99$, $p = 0.003$, with a large effect size as measured by Cohen's d, $d = 1.9$. In contrast, the student pH data gathered with a probe (M = 7.1, SD = 0.7) were not significantly different from the professional pH data, $t(7) = -1.54$, $p = 0.17$.

RQ1b: Student Understanding of Data Quality

We also sought to answer RQ1 by analyzing student responses to the two free-response questions on the pre- and post-intervention survey using content analysis. We received 27 pre-intervention short-answer responses, and 24 post-intervention short-answer responses. Twenty-one of the responses for both pre and post were written by honors biology students; the remainder were written by environmental studies students.

The first author coded the responses to the short-answer questions, looking for themes in the responses, as described in Creswell (2012). The second author then reviewed the first author's codes independently, and we discussed any differences in coding until we reached consensus. Four different themes arose in response to each question; the themes are described and the frequencies recorded in Table 3.

Almost every answer fell under one of the themes; some answers fit in multiple themes, as when a student wrote, "Retake the sample as well as compare with others" on the post-survey, in response to Question 2. The first author coded this as both "Multiple tests" and "Work with others." All of the themes appeared both before and after the intervention.

In response to Question 1, students who defined data quality as "quality of data" on the pre-intervention survey were likely to change the answer or add information on the post-intervention survey. Students who mentioned accuracy as a factor in data quality on the pre-intervention survey were likely to mention it again, but more students used the concept on the post-intervention survey. After the intervention, slightly fewer students defined data quality using the vague words "good" or "well."

Students who wrote about multiple tests in response to Question 2 on the pre-intervention survey were likely to include that strategy again on the post-intervention survey, but the percentage of students who mentioned it increased. The percentage of students who included working with others in some way as a strategy increased greatly on the post-intervention survey.

Table 2. *F*-Tests Comparing the Variances (s2) of Student and Professional Data

Variable	Student		Professional		*p*
	N	s^2	*N*	s^2	
Dissolved oxygen	31	15.63	5	0.37	0.002*
pH (chemical)	32	0.14	5	0.09	0.78
pH (probe)	4	0.43	5	0.09	0.17

Note. Professional pH data were collected with probeware, and compared to both student pH data quantified chemically, in the row "pH (chemical)," and student data collected with probeware, in the row "pH (probe)."

* Indicates significance

Table 3. Themes in Response to Short-Answer Questions on the Pre- and Post-Intervention Survey

Question/Theme	Sample Quote	% pre	% post
Question 1: Define “data quality” in your own terms.			
Quality of data	“The quality of the data you get from doing an experiment.”	37	20
Reliability	“How reliable and how credible your data is.”	15	16
Accuracy	“The data that you collect is correct.”	44	68
Good data	“Data quality is how good the data is.”	22	16
Question 2: Explain how you would make sure you are collecting quality data during any science experiment.			
Multiple tests	“Collect data more than one time to make sure it’s more accurate.”	56	72
Work with others	“Double or triple check your work, corroborate with others doing the same project, if it doesn’t seem right, then do it again.”	7	24
Follow directions	“Make sure you are following all procedures very closely.”	19	20
Control variables	“Make sure you are only testing one variable.”	15	8

RQ2: Student Science Engagement

We compared student engagement before and after the citizen science project in order to note any effect of the intervention on students’ science engagement. Twenty-nine students completed a modified Engagement vs. Disaffection with Learning questionnaire (Skinner et al., 2009) before and after the intervention. Of these students, 21 were biology students, and eight were environmental studies students. We compared the pre- and post-intervention responses on emotional and behavioral engagement using paired, two-sample *t*-tests. The students’ emotional engagement was not significantly different after the intervention, $t(29) = -0.07$, $p = 0.95$; neither was their behavioral engagement, $t(29) = 1.01$, $p = 0.32$. Their pre- and post-intervention engagement is compared in Table 4.

Students’ behavioral engagement was also quantified before and after the intervention using the StRoBe observation tool (Marchant, 1989). We compared each student’s number of appropriate behaviors and inappropriate behaviors before and after the intervention using paired, two-sample paired *t*-tests, as well as confirming that the assumption of normality was met. The students

Table 4. Paired, Two-Sample *t*-Tests Comparing the Self-Reported Engagement of Students Pre- and Post-Intervention

Engagement	*N*	Pre-Intervention			Post-Intervention			*p*
		M	*Mdn*	*SD*	*M*	*Mdn*	*SD*	
Emotional	29	3.0	2.9	0.4	3.0	3.0	0.4	0.9481
Behavioral	29	3.1	3.0	0.4	3.0	3.0	0.5	0.3221

demonstrated higher numbers of appropriate behaviors after the intervention, and the difference was significant, $t(115) = -3.53$, $p < 0.001$. The paired t-test also suggested a significant difference between the number of inappropriate behaviors before and after the intervention, $t(115) = 3.23$, $p = 0.001$. The effect size for both of these differences, as measured by Cohen's d, was relatively small, with $d = 0.33$ for appropriate behaviors, and $d = 0.34$ for inappropriate behaviors. The mean number of inappropriate behaviors was relatively low before and after the intervention, and the standard deviation was high. The pre- and post-intervention observed behaviors are compared in Table 5.

Discussion

Citizen science provides potential benefits to both scientists and non-scientist participants involved in a project. Benefits to scientists include, potentially, a large set of data to manipulate (Zoellick et al., 2012), and benefits to participants have included increases in interest in and/or understanding about various scientific topics (Bonney et al., 2014; Cardamone & Lobel, 2016; Widder et al., 2014). The purpose of this project was to explore how a citizen science project done in a high school classroom could benefit scientists by producing high-quality data, as well as student participants by increasing students' science engagement.

Quality Student-Collected Data, with Caveats

This study shows that when "quality data" is defined as comparable to data collected by professionals, as it is by several other researchers looking at citizen-collected datasets (Aceves-Bueno et al., 2017; Castagneyrol et al., 2020; Parrish et al., 2019; Nicholson et al., 2002), then it is possible for students to collect high-quality data. Students in this project collected dissolved oxygen and some pH data that were not significantly different from professional data. This does not mean that all data collected by students will be of high quality, and there are a variety of factors affecting the quality of student data. Aceves-Bueno et al. (2017) found that two citizen science project variables that correlate with higher-quality data are additional training and large group sizes; Nicholson et al. (2002) indicated that one strength of citizen science programs is in the number of sites that they can monitor. Similarly, the large number of dissolved oxygen (DO) tests done by the students, as compared to the five done by the professionals, allowed the students to have a DO mean similar to the professional scientists', despite the students' larger variance (Table 2). In contrast to this strength of citizen science projects, Nicholson et al. (2002) named more sophisticated equipment as a strength of professional scientists, and in this study, the precision of the equipment played a role in the quality of the student pH tests. The chemical tests that students used to complete the assignment only allow users to record a pH of 6, 6.5, or 7, whereas the probes display a pH with up to two decimal places. This is most likely why the student pH data recorded using the chemical tests were significantly different from the professional pH data, but the student pH data recorded using the probes were not.

Comparability of student data to professional data, therefore, is affected by factors such as sample size and equipment, as well as training (Castagneyrol et al., 2020) and student understanding of data quality (Sheppard & Terveen, 2011). The short-answer questions on the pre- and post-intervention questionnaire were designed to determine whether student understanding of data quality existed, in the case that the sample size or equipment precision were not enough to allow student data to be compared to professional. Student understanding of how to describe data quality as a concept increased some, as more students took to describing the accuracy or reliability of data, rather than how "good" the data were. Students who took the survey already had a good foundation on ways to ensure data quality, but they wrote more about working with other students and about performing multiple tests after the intervention. The understanding of multiple

Table 5. Paired, Two-Sample t-Tests Comparing the Observed Behaviors of Students Pre- and Post-Intervention

Behavior	*N*	Pre-test		Post-test		*p*
		M	*SD*	*M*	*SD*	
Appropriate	116	9.11	2.68	9.96	2.38	>0.001*
Inappropriate	116	1.34	1.99	0.76	1.42	0.001*

tests and controlling variables that existed before the intervention may be related to the fact that the majority of the students who answered the short-answer questions were biology students, who had already had some lessons on experimental design at the beginning of the school year.

Stagnant Emotional Engagement, Increased Behavioral Engagement

Past studies on citizen science have shown youth participants to gain interest, which is a dimension of engagement, in science and/or their own environment (Bonney et al., 2014; Cardamone & Lobel, 2016; Widder et al., 2014). Past studies on student engagement have found that relevance (Hulleman & Harackiewicz, 2009) and challenging activities that nonetheless allow students agency (Olitsky, 2007) increase science engagement. These findings would suggest that a citizen science project in the classroom would have the potential to increase student engagement in science. Despite this, there was no difference in student self-reported engagement, either emotional or behavioral, before and after the intervention. There were, however, changes in the observed behavioral engagement, with the number of appropriate behaviors observed increasing and the number of inappropriate behaviors decreasing.

There are multiple potential reasons for this less-than-expected effect on engagement. Both the emotional and behavioral self-reported engagement were high before and after the intervention, falling around a 3 on a four-point scale (Table 4). This could be because, although the survey was anonymous, students felt that they should score themselves as highly engaged on a survey being given by their teacher. Or, it could be that the students who took the survey were actually very engaged in class both before and after the intervention. Because of an unexpected disruptive event in the school system that happened after the interventions and observations were complete, but before the post-intervention surveys had all been sent out, fewer students responded to the post-intervention surveys than participated in the rest of the project; the students who did respond were mostly students in the honors biology classes, which means that they were already tracked based on their achievement in science, and generally demonstrated higher engagement than their peers in the environmental science classes.

Interestingly, this lack of reported change in student emotional engagement, which fails to align with past research on citizen science showing an increase in participant interest in science, highlights the observed change in behavioral engagement—a variable less often studied in papers focused on citizen science. In contrast to the self-reported behavioral engagement, observation of the students' behavior did show a change before and after the intervention. Their number of appropriate behaviors, out of twelve per observation, increased after the intervention, and the difference was significant. Because the first author was able to observe all her students, including in the more diverse environmental studies classes, it is likely that these observations are of a real increase in behavioral engagement from students who started out as less engaged in their science classes.

Limitations

This study has some legitimate and interesting findings, but they are not without limitation. Though student and professional data were collected in a similar timeframe, and there were variables that were comparable, there were variables collected by the professionals and not by the students, and vice versa. Also, because students and professionals were not working side-by-side on the exact same date, there may have been differences caused by temperature or weather in the true pH and true dissolved oxygen levels of the stream (Dodson, 2005). Variations in method used by students vs. professionals could also have led to differences in the datasets, as seen in the difference between student pH data collected using different tools. More coordination between student and professional data collection would allow a more stringent comparison when considering data quality.

With respect to results on student engagement, events in the county meant that fewer students than would have been ideal were able to respond to the post-intervention survey, limiting those responses to mainly those from honors biology students, though all the students participated in gathering water-quality data and in the pre- and post-intervention observations. The population of students who participated in the study was limited in a different way by the location of the school where the study took place. The students in question were mostly White students, and the high school where they completed the intervention is in a very rural area, where many of the students spend much of their free time outdoors. It is likely that the outdoor aspect of the study increased its relevance for some students, and increased relevance has been shown to at least increase emotional engagement in the past (Hulleman & Harackiewicz, 2009). Whether a similar intervention would be as directly relevant for students in a more urban setting is worth exploring.

Implications

The limitations and findings of this study lead directly to implications for scientists, researchers concerned with citizen science, and educators in ISE and FSE settings. The first and simplest implication is that it *is* possible to gain both quality data and increased student engagement from a citizen science project in a classroom. Considerations must be taken with this conclusion. In the case of this project, we have operationalized "data quality" as data similar to that collected by professional scientists. Future citizen science researchers and program creators have multiple options regarding future consideration of data quality. The first would be to hold firmly to that operationalization of data quality, and to do more stringent and purposeful work in order to compare student/participant data to professional data, including planning ahead of time to ensure the similarity of the variables collected by scientists and citizens. The second would be to reconsider the definition of data quality. Aceves-Bueno et al. (2017) point out that scientists can have different standards for data quality depending on the specific study purpose; in this case, students found, on average, the same numbers for dissolved oxygen as professionals did, but with a much higher variance, which might be acceptable in a citizen science study intended to compare several streams, but not in one intended to record small variations in one stream over time. Wildschut (2017) goes further in an essay calling for the need for a new prevalence and value given to citizen science; she points out that not only does the meaning of data quality depend on what the data are to be used for, but data are only useful at all when accessible to those who need them, and citizen science is traditionally more available than professionally published data. Educators and/or program developers as well as researchers must consider carefully what they mean when they consider whether citizens are able to collect high-quality data.

In this study, students were more easily able to collect high-quality pH data—i.e., data similar to that collected by professionals—when they used tools similar to those used by the professional scientists. This finding has implications not only for future citizen science project coordinators focused on usable datasets, but on student outcomes as well. Using real, local datasets and complex authentic technology has been found to positively impact students' interest in and knowledge about local watershed issues (Marcum-Dietrich et al., 2021), and student technology usage in a science, technology, engineering, and mathematics (STEM) setting is related to their engagement in STEM (Kareem et al., 2022). If the use of more sophisticated technology has the potential to lead to higher-quality data and support student science engagement, these goals are not necessarily in conflict, but can be mutually supported during an educational citizen science project.

Even without access to sophisticated technology, it is worth designing a citizen science project in an educational setting if it will lead to student engagement. Engaging students in science in order to potentially lead them to competitive science or technology careers has been more and more touted in the literature of the last few decades (Kennedy & Odell, 2014). However, even students who will not grow up and go on to science careers can benefit from becoming engaged with science as a subject and process. Adults engaged in citizen science report more knowledge of science processes and are more likely to work to bring others into contact with science, in comparison to peers who are science hobbyists (e.g., birdwatchers) but not citizen scientists (Jones et al., 2018). And as we wrote in the introduction, student engagement in the science classroom has already been tentatively linked to future adult PES (Lin et al., 2012). In order to assist with the goal of PES for students both in and beyond the classroom, future research considering citizen science in an FSE setting must continue to consider multiple domains of student engagement—behavioral and emotional, as well as cognitive, social, etc. (Fredricks et al., 2016)—not only repeating the measures used in this study, but doing qualitative work to learn why engagement does or does not change as the result of a citizen science project. Also of interest are the long-term effects of a citizen science project; if students do become more engaged, or interested in, science, or if their connection to nature or content knowledge is changed (Evans et al., 2005; Haywood, 2016), then do these results truly last? Can citizen science projects with youth lead to adults who are publicly engaged with science?

Conclusion

Citizen science is a practice that offers many potential benefits to both scientists and the citizens who participate in it. This research highlights some of those benefits, as well as some of the factors that impact the effectiveness of any one citizen science project. In this study, students understood how to ensure data quality, based on experience and direct instruction, but were limited in the quality of the data they collected based on factors such as equipment. While students' self-reported engagement in science stayed constant, their observed behavioral engagement increased, a finding counter to research suggesting increased self-reported interest as the result of citizen science (Bonney et al., 2014; Cardamone & Lobel, 2016; Vitone et al., 2016; Widder et al., 2014). These findings offer guidance to scientists and educators looking to develop future citizen science projects for an FSE setting. The need for scientific literacy in the general populace continues to increase in the public consciousness; citizen science projects done with youth have the potential to lead to a new generation of scientifically literate citizens. Citizen science can provide useful data for scientists, increase the engagement of student participants, and eventually lead to more adults publicly engaged with science, and a brighter future for us all.

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Data Accessibility

The participants in this study did not give written consent for their data to be shared publicly, so the data are not publicly available.

Competing Interests

The authors have no competing interests to declare.

Author Contributions

The authors confirm contribution to the paper as follows: study conception and design, data collection: EB. Analysis and interpretation, draft manuscript conceptualization and preparation: EB, H-LL. Both authors reviewed the results and approved the final version of this manuscript.

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