



# Actively Participating in University-Sponsored Ecological Research Increases High School Students' Knowledge of and Attitudes About Science

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The Next Generation Science Standards call for students to “investigate the natural world through the processes of scientific inquiry.” Yet, it is rare for secondary students in the U.S. to engage in authentic scientific investigations of natural phenomena. The Columbia River Estuary Science Education and Outreach (CRESCENDO) Project was a 2-year (2016–2018) university-high school partnership between scientists and science education researchers from Washington State University (WSU) and science teachers and students from five public high schools located adjacent to the Columbia River Estuary (CRE). The teachers and students collaborated with WSU scientists on a rigorous ecological study of the CRE, which provided an opportunity to study how engaging students in authentic scientific research would impact their ecological knowledge and their attitudes toward environmental stewardship. Our study methods included online attitude surveys and knowledge assessments for all participating students, classroom observations, and semi-structured small group interviews with 3–5 students from each school at the end of each year of the project. We found that many students made significant gains in their ecological knowledge and understanding of scientific inquiry practices, demonstrating deeper understanding of the connections between local land use and water quality in the CRE, as well how nutrient concentrations vary seasonally and along the axis of the estuary. Students also showed enthusiasm for taking part in a “real” scientific research project, collaborating with university scientists, contributing “their” data to an investigative effort that extended beyond their own school, and the opportunity to get outdoors during science class. We identified five “key elements” of the CRESCENDO project that contributed to its success, and which would allow our model of a consistent, long-term (months) and immersive research experience for high school students to be transferrable to university-school partnerships across a range of size, location, research mission, and resource availability. Finally, this project also provided more evidence in support of place-based approaches for student learning, and the importance of immersing students in their environments where they can study the natural world by asking relevant questions and generating novel data about the science topics that matter to them.

**Keywords:** environmental education, university-school partnerships, estuaries, transdisciplinary research, aquatic ecology

## INTRODUCTION

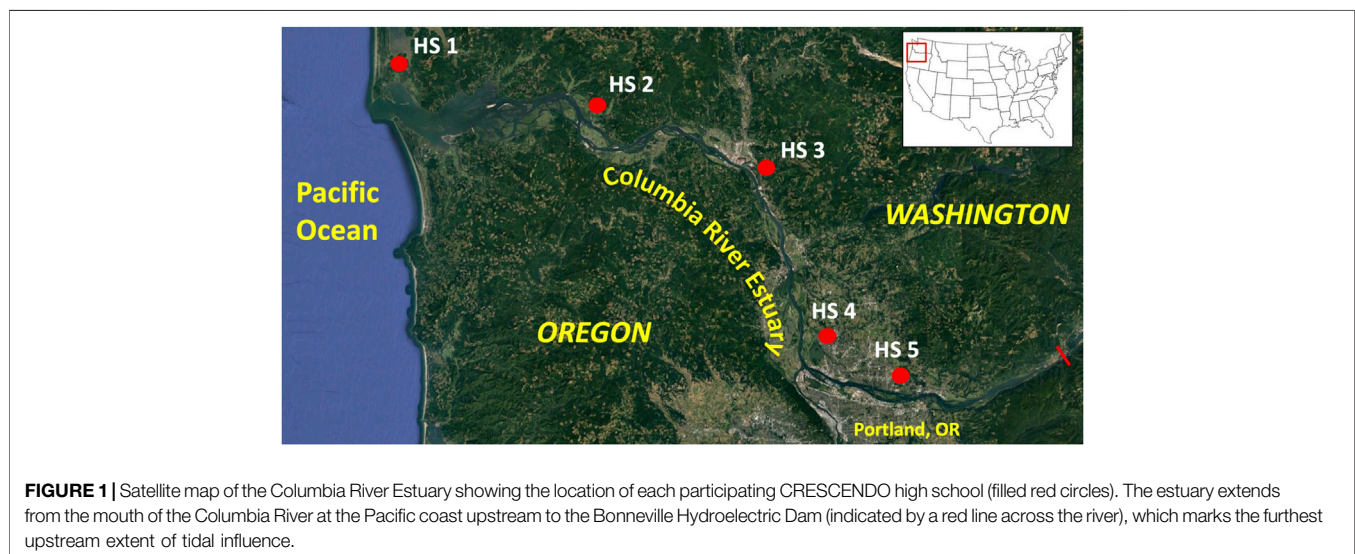
The Next Generation Science Standards for K-12 science education call for students to “investigate the natural world through the processes of scientific inquiry” in order to define natural systems, identify the boundaries and interactions within an ecosystem, and develop models to explain interactions and cause-effect relationships (Achieve Inc., 2013). Yet, secondary students in the U.S. have few learning opportunities that involve authentic scientific investigations of natural phenomena (Banilower et al., 2010; Trygstad et al., 2020). In response to this need, we developed the Columbia River Estuary Science Education and Outreach (CRESCENDO) Project as a unique and transferable, 2-year university-high school partnership between aquatic science and science education research faculty on the Vancouver, WA, campus of Washington State University (WSU) and science teachers and their students from five public high schools located in southwest Washington and adjacent to the Columbia River Estuary (CRE) (Figure 1).

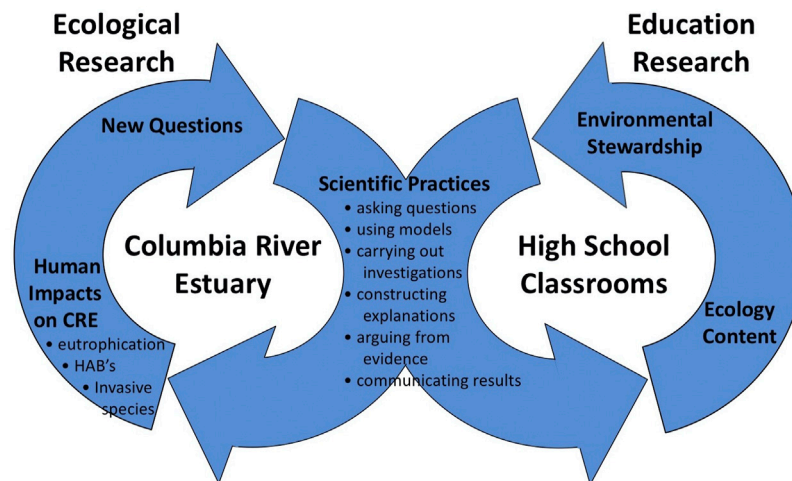
The teachers and students collaborated with university scientists on an intensive and rigorous ecological study of the estuary that provided opportunities for students to engage in authentic scientific inquiry and scientific practices, which we predicted would impact students’ understandings of scientific concepts and their understanding of science as a human endeavor (Rahm et al., 2003; Peker and Dolan, 2012). We intentionally situated this environmental research in the CRE, a place located in the students’ own neighborhoods and thus personally familiar and relevant for them, and where the aquatic ecologists on our team have on-going scientific research. Such place-based engagement holds the potential for increasing students’ understandings of the connections between human activities and decisions and environmental health, and possibly raising their interest in environmental stewardship (Bouillion and Gomez, 2001; Radinsky et al., 2001; Preston and Griffiths, 2004; Shume, 2016; Semken et al., 2017).

Oriented around the intersection between ecological and science education research in the CRE, this partnership project encompassed the problems of potential impacts on estuaries of invasive aquatic species, algal blooms, and nutrient inputs from land use activities related to urbanization—each a critical environmental problem influenced by climate change (Grimm et al., 2008). The partnership also addressed the challenges of educating the next generation of scientists (Achieve Inc., 2013) and cultivating citizen environmental stewardship more broadly (Dickinson and Bonney, 2012). Indeed, the need for community-based, interactive and participatory research projects focused on the CRE and other large river estuaries is acute, given that estuarine ecosystems exist at the confluence of rivers and oceans, as well as the confluence of human populations whose activities impact watersheds and increase eutrophication and the introduction of aquatic invasive taxa (Collins et al., 2011). To inform and advance environmental restoration projects, recovery efforts, and preventative measures, a wide spectrum of research approaches are needed, many of which can and should include strong educational components. Such models of transdisciplinary research are increasingly recognized as critical for addressing broad and complicated environmental problems that require collaboration between scientists, engineers, social and political scientists, educators, and citizens (Liu et al., 2007; Lang et al., 2012).

## Conceptual Framework for Integrated Educational and Scientific Research

We developed a conceptual model around which to frame our research approaches that explicitly incorporated the foundational principles and practices of scientific inquiry (i.e. questioning, observation and experimentation, analysis and interpretation, and communication with peers), as well as the educational research goals of understanding how students learn scientific knowledge and skills, how teachers effectively engage students to achieve such learning, and how this may influence students’ sense of environmental stewardship (Figure 2). In this scheme, the link





**FIGURE 2** | Conceptual diagram illustrating the intersection between the processes of ecological research of the CRE and of high school science teaching and learning. “HAB’s” refers to harmful algal blooms.

between these two research cycles is the collaborative participation by professional scientists and researchers, and high school science teachers and students, in the practices of science.

Using this conceptual model, we designed the framework of the CRESCENDO project to explicitly link two overarching research themes:

- What are the links between upstream watershed processes, land use practices, and downstream estuarine ecology, as indicated by nutrients, harmful algal species, and invasive zooplankton in the CRE?
- What are the links between high school students’ understanding of CRE ecology, their participation in authentic scientific research, and their perceptions of and attitudes toward the CRE landscape and science more generally?

In this article we describe our results and conclusions in relation to the overarching educational research theme. We direct readers to our recent peer-reviewed publication describing the results of the scientific research conducted in the CRESCENDO project, which show a distinct geographic pattern in the resident zooplankton assemblage of the CRE between the marine-influenced river mouth at the Pacific coast compared to the freshwater (yet still tidally-influenced) upstream reaches of the estuary, where the invasive copepod *Pseudodiaptomus forbesi* now comprises >50% of the zooplankton abundance (Connelly et al., 2020). Notably, all of the samples and data analyzed and reported in this article were collected and initially processed by the CRESCENDO high school student participants.

## Educational Research Questions

This 2-year partnership with teachers from five high schools provided an opportunity to study the impact of students’ engagement in authentic scientific research on their understandings about the ecology of the CRE and the practices used by scientists to develop scientific knowledge.

We were also interested in whether learning about their local environment influenced their attitudes toward environmental stewardship. We asked the following specific research questions in order to investigate these themes:

RQ1: How does participation in a university-high school research partnership influence students’ understanding of the CRE as part of a larger ecosystem?

RQ2: What do students learn about scientific practices, especially related to data collection, data analysis and evidence-based reasoning (e.g., their use of data to explain or model ecosystem dynamics), as they engage in authentic scientific research?

RQ3: What connections (if any) do students make between scientific understanding and environmental stewardship? How does this impact students’ attitudes about stewardship of the CRE?

RQ4: Which aspects of the CRESCENDO project are perceived as most meaningful and/or notable by the students, and in what ways do these aspects influence students’ interest in and perceptions of science, scientists, and scientific work?

## Geographic Setting

We chose to focus our place-based partnership project on the CRE due to its significant influence on the economic, cultural and environmental vitality of western Washington state, as well as the estuary being a central focus of on-going ecological research being conducted by aquatic scientists at WSU Vancouver. Specifically, the CRE is the largest river estuary on the US Pacific coast based on annual discharge (Simenstad et al., 1990), and is the site of a rapidly growing metropolitan area with major shipping ports and associated infrastructure that support many different local economies, including commercial and recreational fisheries as well as tourism. Land use in the CRE region consists of expanding urbanization and residential development surrounding the upper reach of the estuary (associated with the cities of Vancouver, WA, and Portland, OR) and heavily forested and agricultural lands

surrounding the lower estuary (**Figure 1**). Thus, there is a distinct difference in human population size, land use and socioeconomic base between the upstream and downstream portions of the CRE: high population and urban development and a growing technical industry near Vancouver in the upper reaches, and a smaller population and greater reliance on harvesting of natural resources (e.g. commercial logging and fishing) along the lower reach of the estuary.

## CRESCENDO Participants and Project Structure

We have previously published detailed descriptions of the CRESCENDO project design, including lessons learned and recommendations for future implementation (Rollwagen-Bollens et al., 2019), however here we provide the key elements specific to the educational research approaches and protocols.

The CRESCENDO project ran from August 2016 to September 2018, as a partnership between research faculty at WSU Vancouver and teachers and students from five high schools located along the CRE (**Figure 1**). These schools were selected based primarily on them being roughly equidistantly spaced along the 180-km length of the CRE, and also to reflect a range of student population size, community type (e.g. rural, suburban, etc.), socioeconomic character, and surrounding land use patterns. This allowed us to meet the scientific research requirement of distributed sampling within the CRE, as well as the opportunity to compare outcomes of this place-based project among schools that varied in these community characteristics.

## Demographic Profiles of Participating Schools

**Table 1** shows the student demographic data collected from each school by the Washington Office of the Superintendent of Public Instruction and posted to their public website (<https://www.k12.wa.us/data-reporting/data-portal?combine=Report%20Card%20Enrollment>). Note that all schools, teachers and students in this article are referred to by pseudonyms. The data in **Table 1** reflect the demographics of the entire student body in each school during the 2017–18 academic year, the second year of the CRESCENDO project and the year during which most of our own data collection occurred. We did not ask individual student participants to share their race or ethnicity, nor their socioeconomic status on any assessment, survey or interview; however, our classroom observations suggest that the demographic profile among students who participated in CRESCENDO were generally representative of their school's overall student population.

There were differences in the student demographic profiles for high schools located in the lower estuary (Opportunity, Creek, Waterside) compared to those located in the upper estuary (Northwest, Riverbend). On average, the three lower estuary high schools consisted of White (80%), Hispanic/Latino (12%), and low income (56%) students, as well as students experiencing

homelessness (11%). By contrast, the two high schools located in the upper estuary region consisted (on average) of White (76%), Hispanic/Latino (11%) and other people of color (6%), with fewer low-income students (31%), and one school (Northwest—a public “school of choice”) with a high proportion of highly capable students (86.4%).

## Teacher Recruitment and Support

Prior to the start of the project, we contacted one or more science teachers at each high school to inquire about participation in CRESCENDO. Criteria for selection included having a minimum of 5 years teaching experience at that school, currently teaching a biology, chemistry, ecology, environmental science, or natural resources course, and experience implementing curricular and pedagogical approaches aligned with the Next Generation Science Standards (Achieve Inc., 2013). We ultimately recruited one teacher at each of the five high schools to participate in both years of the project; however, the teacher at Waterside High School left his position early in the first academic year due to a family emergency and his position was not filled until the next academic year.

Each teacher received a \$2,000 stipend for each year of their participation, and their school was provided with a complete set of sampling equipment, including plankton net, hand-held electronic temperature and conductivity profiling instrument, and water quality test kits. In addition, the project equipped each teacher's classroom with a stereomicroscope with built-in video camera for observing plankton samples. All equipment became permanent school property at the end of the project term.

## CRESCENDO Project Activities and Schedule

**Teacher workshops.** In August 2016 and 2017, prior to the start of each academic year, all teachers participated in a 1-day workshop on the WSU Vancouver campus, including field sampling training sessions conducted from a nearby dock on the CRE (the same dock that was later used by the Northwest teacher and students for their monthly sampling events). The teachers also spent time learning about the rationale and specific research questions of the CRE ecological study, and contributed to framing the questions so as to be accessible to their students. In addition, the teachers worked with the WSU science education researchers to identify topics within their existing curricula that would best link to the CRESCENDO project. Finally, the teachers collaborated with each other to develop shared plans for incorporating the project work into their classes, as well as for implementing surveys and group interviews with their students over the course of the upcoming academic year.

**Monthly field sampling and data collection.** The field sampling component of the CRESCENDO project occurred between October and May of each academic year. In the third week of every month, teachers brought their students to a dock on the CRE located within a 15- to 20-min walk or bus ride from their school. At the dock, the teachers supervised their students as they followed strict sampling protocols designed by the WSU Vancouver scientists to conduct replicate plankton tows, vertical



**TABLE 1 |** Demographic profiles of students who attended each CRESCENDO high school during the 2017–18 academic year.

	HS 1 “Opportunity”	HS 2 “Creek”	HS 3 “Waterside”	HS 4 “Northwest”	HS 5 “Riverbend”
Total enrollment	270	154	1,655	213	1,059
Gender (%)					
Female	46.3	40.9	48.5	36.6	45.9
Male	53.7	59.1	51.5	63.4	54.1
Race and/or ethnicity (%)					
American Indian/Alaskan Native	1.5	1.3	2.0	0.5	0.8
Asian	1.5	0.6	1.0	4.2	2.7
Black/African American	0.0	1.3	0.5	2.3	1.0
Hispanic/Latino of any race(s)	12.6	7.1	15.4	11.3	10.2
Native Hawaiian/Pacific Islander	0.0	0.0	1.0	1.4	0.3
Two or more races	4.4	3.2	6.6	6.1	7.2
White	80.0	86.4	73.6	74.2	77.8
Socioeconomic status (%)					
Low-income	57.4	57.1	53.7	27.7	34.9
Homeless	15.6	14.3	2.5	0.5	2.1
Other categories (%)					
Highly capable	8.9	6.5	7.2	86.4	6.4
English language learners	3.0	3.9	4.1	1.9	2.4
Migrant	4.4	0.0	0.4	0.0	0.1
Military parent	1.5	0.6	0.1	0.9	1.4
Mobile	5.2	5.2	6.3	2.8	3.5
Students with accommodation plans	8.1	5.2	4.2	11.3	5.2
Students with disabilities	16.7	24.0	12.6	2.3	15.2

profiles of temperature and salinity, and measurements of surface water for dissolved oxygen and nutrient concentrations using portable chemical test kits. Each month the teachers kept one plankton tow sample for the students to examine, and sent the remaining replicate tow samples, along with their water quality measurements, to the WSU Aquatic Ecology Lab for compilation and additional analyses. WSU Vancouver scientists conducted the monthly sampling at each school’s dock from June to September each year.

**Curriculum integration.** The CRESCENDO teachers integrated project work into their curricula in various ways, depending on the course. The Northwest teacher focused his chemistry students on the physical properties of the water in both data collection and analysis, and his biology students on the biological aspects. The Riverbend teacher designed a seamless integration of estuarine ecology content into her marine biology course, and added plankton identification into the taxonomy unit and the ecosystems unit in biology. The teacher from Creek taught a career and technical education (CTE) course (Natural Resources) that involved students in an “Envirothon” competition focused on agricultural soils and water. Thus, their participation in CRESCENDO provided authentic experiences in a number of scientific practices, as well as data related to aquatic ecology for their oral presentation. He also integrated CRESCENDO into his environmental science class, with a focus on having his students look at and talk about the data, as well as making connections to many of the students’ jobs in aquatic-related industries in nearby Willapa Bay. The Opportunity teacher also integrated aspects of the project in his environmental science and his chemistry classes. He explained the connection of this authentic work to his chemistry curriculum, saying:

We were hitting valence electrons and polyatomic ions, and we were getting the oxidation numbers for phosphates and nitrates. And we were just going out to test that in the field. So it was a great segue to just talk about how... those things that you read about in the textbook and you sit there and do, practice over and over, have real impacts on our ecology and all that—Kelly, Opportunity teacher.

This teacher also noted the power of the connections between the CRE study and the students’ lives:

A big applied part that was fun for us was talking about the invasives. Because they’re so curious about the ships and it’s just a daily event and they run their jet skis right in front of it, it was a segue of talking about ballast tanks and ships, and tying that economic piece with environmental. I found them asking me throughout the year as they’d collect all the plankton with the tows and stuff—Kelly, Opportunity teacher.

**Annual CRESCENDO Research Symposium.** In May or June of each academic year of the project, each teacher and 5–30 of their students were invited to the WSU Vancouver campus for a 1-day Symposium focused on reviewing, analyzing and constructing explanations and interpretations of that year’s scientific data compiled from all the schools’ monthly sampling efforts. Prior to each Symposium, students from each school worked with their teacher to visualize and make preliminary interpretations of their data, and then student representatives presented their results at the Symposium to the

entire group of CRESCENDO students, teachers, and WSU Vancouver scientific and educational researchers. The presentations were followed by small group sessions (facilitated by WSU Vancouver Environmental Science graduate students) in which high school students examined sub-sets of the data, and then reported back to the larger group for a wider discussion to interpret that year's results.

## MATERIALS AND METHODS

### Educational Research Approach and Methods

We employed a mixed methods research design and analytical approach (Creswell, 2014) to address our four educational research questions, consisting of quantitative pre- and post-academic year assessments of ecological knowledge and surveys of student attitudes, along with qualitative analyses of student responses during small group interviews. All of our protocols were reviewed and approved by the WSU Institutional Review Board for research involving human subjects, including children.

We designed the knowledge assessment and attitude surveys for the CRESCENDO project based on review of published evaluation approaches and instruments (Dunlap et al., 2000; Siegel and Ranney, 2003; Bramston et al., 2011; Larson et al., 2011; Dijkstra and Goedhart, 2012; Bergman, 2016) and in consideration of our specific research questions. While informative, no single model for instrument development was directly applicable to our project goals; therefore, we used an iterative approach of feedback and review of questions within our investigator team to develop and deploy our own survey and assessment.

Each of the 25 scientific knowledge assessment items was formatted as a statement to which the students could choose "true," "false" or "not sure." On the attitude survey instrument, students were presented with 26 statements to which they could respond on a 5-point Likert scale in an agree/disagree format. For both the assessment and attitude survey instruments, questions were grouped into distinct content or thematic categories that allowed for asking questions about the same content/theme in multiple ways. All surveys and assessments were delivered to the students near the beginning of the academic year and again at the end of the academic year *via* a secure online form using the Qualtrics platform.

Prior to all analyses, a member of our team not involved in examining the educational data de-identified all survey and assessment responses by replacing students' names with numeric codes. The results were compiled across all schools, as well as disaggregated by school. For the knowledge assessments, we calculated the percentage of students who answered each true/false question correctly on the pre-assessments and post-assessments, and measured gains (or losses) in the percentage of correct answers after participation in the CRESCENDO project by subtracting the pre-percentages from the post-percentages. We tested for significant differences in pre-post assessment scores within each school, using paired

t-tests of counts of correct answers (since sample sizes were within 2% of each other from pre-test to post-test in each school). We then used ANOVA and Tukey's multiple comparison tests to assess differences in correct score gains/losses (post-assessment—pre-assessment) among all three schools.

We made similar comparisons between students' responses on the pre- and post-academic year attitude surveys by calculating the percentage of students who agreed, disagreed, or were neutral about each statement, and measured the change in the percentage of "agree" responses after participating in the CRESCENDO project by subtracting the pre-percentages from the post-percentages. We tested for significant differences in pre-post surveys in the same fashion as described above for knowledge assessments, using Likert-scale scores as interval data, which qualifies for parametric techniques such as paired t-tests and ANOVA (Norman, 2010).

Qualitative data also informed our results. In April and May of each academic year, we conducted semi-structured interviews with small groups of students (three to four students per school). We used a purposeful process to select students for these group interviews, based on input from the teachers about their students' level of engagement in the CRESCENDO project activities. Such a process allows for developing a rich data source to inform understanding relevant to educational research questions, which goes beyond the products of student learning (i.e., test score gains) to explore and expand upon the processes of student learning (Glesne, 2010).

The small group interview questions were developed in relation to our research questions, with open-ended prompts to "talk about" what they were learning (RQ1); if what they were doing was different or the same as other science classes they had taken (RQ2); and how the project work influenced their interest in science, careers, or the environment (RQ 3 & 4); and anything else they valued about the project. Interviews were led by a WSU Vancouver educational researcher and a graduate student. This sub-set of students voluntarily participated in the interviews and signed individual consent forms, along with their parents and/or guardians. The group interviews were audio-recorded and later transcribed by an external transcription service, and then students' names replaced with pseudonyms in the transcriptions.

Transcripts from each of the 2 years were analyzed to discern patterns in what students learned and valued, as well as their attitudes and perceptions about their experiences while participating in the CRESCENDO project. For the first cycle of analysis, the first two authors individually coded one interview transcript, generating descriptive and concept codes and analytic memos to capture emerging theories (Miles et al., 2014). Codes were discussed and refined before moving on to another transcript; this process continued until the group interviews from both years were coded. This first cycle resulted in an initial set of agreed upon codes and sub-codes, such as "learning: through data analysis," "learning: about the CRE," "learning: about data collection," "science is real," and "how the teacher enacted the project." We conducted a second cycle of coding together to synthesize codes into larger categories, develop precise descriptions of each category and code, and generate combined analytic memos. We organized codes and

categories within and across schools and school years into a spreadsheet and identified patterns in relation to each research question.

Additionally, descriptive coding of teacher interviews at the end of the first year, and transcripts of their reports to each other and the project team early in the second year, provided background information that explained or triangulated students' responses in their interviews.

## RESULTS

Here we present the results of the pre-post knowledge assessments and attitude surveys from the 2017–18 academic year, as well as end-of-year student focus group interviews from both years of the project (2016–17 and 2017–18), for three of the participating high schools: Opportunity, Creek, and Northwest. We have excluded the other two schools' data from the analyses due to very low pre-post survey and assessment responses, resulting from external limitations on those teachers' opportunities to incorporate the project sufficiently into their curriculum. In addition, there were substantial unexpected logistical challenges of weather and dock infrastructure near one school that made it impracticable (and at times unsafe) to include their classes in the field sampling program. We opted, therefore, to focus our analyses on the schools with comparable levels of curricular integration, as well as those where entire classes of students engaged in the field sampling, data processing and data interpretation. We do note, however, that the teachers from Waterside and Riverbend high schools were able to successfully maintain the monthly field collections for their locations, with the regular assistance of a small number of dedicated students (and occasionally their enthusiastic parents). This continuity of sampling allowed for the successful completion of the CRESCENDO scientific research investigation (Connelly et al., 2020). Overall, teachers from all five schools engaged more than 300 high school students in the CRESCENDO project.

### Online Knowledge Assessment and Attitude Survey Respondents

We collected responses from a total of 65 students (Opportunity: 18, Creek: 19, Northwest: 28) in early January 2018, and a total of 63 students (Opportunity: 21, Creek: 18, Northwest: 24) in late May 2018. On average, the respondents to both sets of online assessments/surveys were 62% male and 36% female, and 64% were in 11th grade. The majority of students had previously completed two to four science classes in high school prior to the 2017–18 academic year, 80% of which were life science with the remainder mostly physical science, environmental science, or robotics. The ratio of boys to girls among the assessment/survey respondents shown above closely aligned with the gender ratio among the total student populations across all three schools (58% male; 42% female).

### Focus Group Interview Participants

In April and May 2017, we conducted group interviews with four students each from Opportunity, Creek, and Northwest high

schools (12 students in total). The groups from Opportunity and Northwest were both 50% male and 50% female, and at Creek the group was 75% male and 25% female. During the group interviews conducted in April and May 2018, the group profiles were more mixed, with three male students participating from Opportunity HS, three male and one female students from Creek HS, and three male and two female students from Northwest HS. The ratio of boys to girls among our focus group participants also closely aligned with the overall gender ratio across all three schools. We did not gather any other demographic data from the students who responded to assessments and surveys, nor those who participated in the focus group interviews.

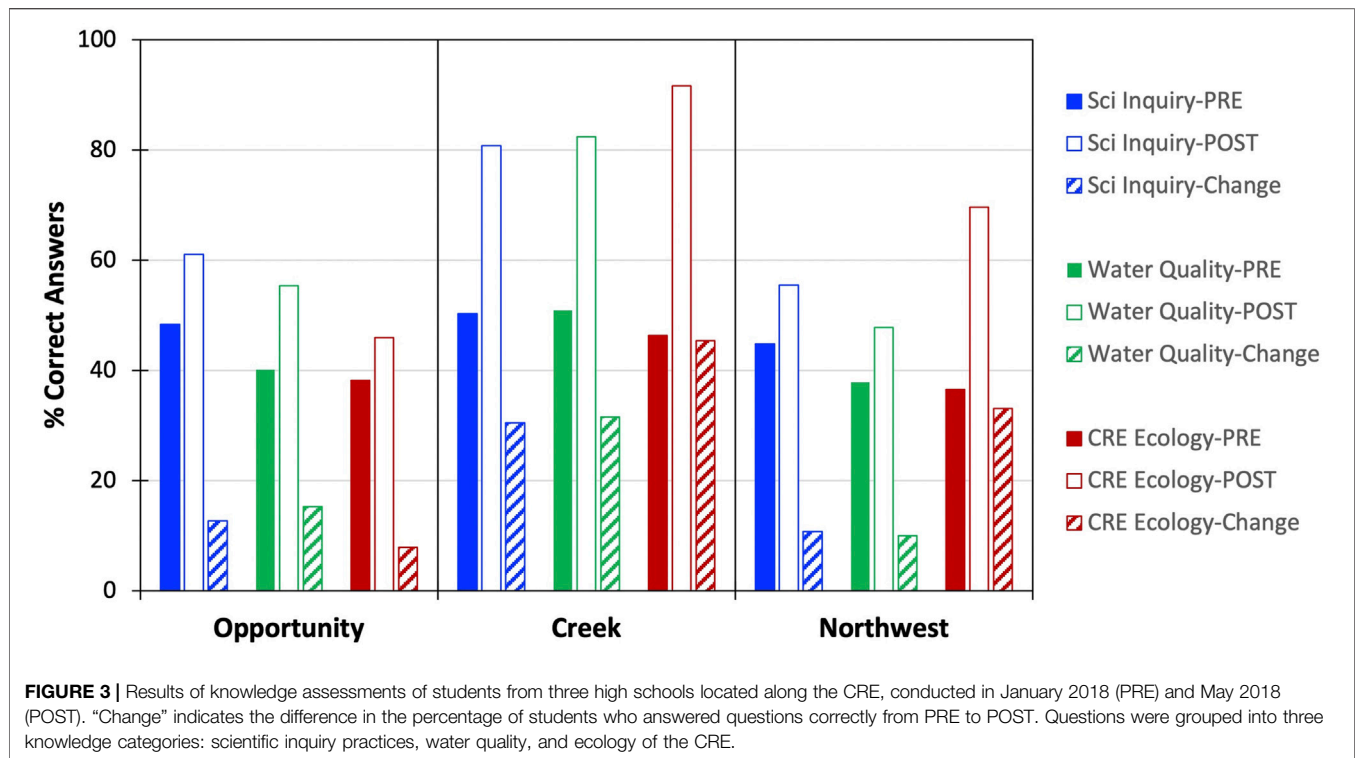
### RQ1: How Does Participation in a University-High School Scientific Research Partnership Influence Students' Understandings of the CRE as Part of a Larger System?

Students from all three high schools who completed the 25-question knowledge assessments in 2018 demonstrated significant ( $p$ -values in all cases  $<0.01$ ) gains of 10–45 percentage points from pre- to post-assessment on the proportions of correct answers to questions related to water quality and ecology of the CRE (Figure 3).

The greatest ecological knowledge gains for students participating in the CRESCENDO project were related to the role of nutrient levels on algal growth and the biology of copepods, the most common zooplankton taxa present in the plankton tows they examined. There was also a striking difference in the magnitude of knowledge gains among the schools, despite students in each school beginning at approximately the same level (~42% correct answers on pre-assessments). Students from Creek HS increased to 82–92% of questions correctly answered on post-assessments, while students from Opportunity and Northwest gained an average of 17% percentage points, to a level of ~55% correct answers (Figure 3). The gains from pre- to post-assessments for students from Creek HS was significantly higher than for Northwest ( $p < 0.0001$ ); similarly, the gains observed at Opportunity HS were also significantly higher than for Northwest ( $p = 0.026$ ).

The responses of students in the small group interviews during both years indicated that one of the most common ways that students gained ecological understanding of the CRE was through their ability to make connections among various components of the ecosystem. Of the 26 sets of comments across all six interview sessions that were coded in relation to this research question, 65% were observations about water quality at their sampling site and aspects of the lands surrounding it, as well as facts they already knew about but had not previously associated with their new ecological knowledge.

“(As) I was saying ... There was a high amount of nitrate in Vancouver. And so I was like, OK, was there also a high amount of nitrate in our town? ... I looked, I



was like, OK, yes. So is there any problem environmentally with it? And there was actually a high amount of red algae in the Columbia River, which caused the river to look very red in Astoria. And red algae actually need nitrate. And if there’s a lot of nitrate, there’s a lot of red algae. And so that’s what I found out.” — Megan, Northwest HS.

“I thought it was cool to see like, Vancouver, which has a lot more pavement in city areas than we do compared to a place like us. So you match up a city like us with lots of forests, a lot of farming land and you match it up with the city like Vancouver, which is a lot of industrial and urban stuff, you see how the water changes and what’s different each place. I thought that was really cool.” — David, Creek HS.

Shane: “I personally appreciate how we’re using real data to test real problems as well. With Robin’s and I’s topic, if there’s way too much phosphate in just the agricultural areas obviously there’s something wrong with how they’re doing agriculture in those areas and they’re making the phosphate way too high.”

Robin: “Phosphates are important because they can lead to algae blooms.”

Shane: “And basically the suffocation of fish . . .”

Robin: “The plant life goes out of control because they readily absorb and use phosphates, so they promote that growth.”

Shane: “Where the water becomes way too mossy. . .”

Robin: “So you need those plants because the water needs a certain level of plants and the ecosystem needs them. But if you have too many then you can’t support any marine life. It’s important that if you have too high levels of phosphates then you basically create this dead zone where nothing but plants can live, so it has a huge impact on the river.” — Shane and Robin, Northwest HS.

## RQ2: What did the Students Learn About Scientific Practices, Especially Related to Data Collection, Data Analysis and Evidence-Based Reasoning (e.g., Their Use of Data to Explain or Model Ecosystem Dynamics), as they Engaged in Authentic Scientific Research?

We designed CRESCENDO to actively engage students in ecological research and support their understandings of and abilities to enact scientific practices. The student activities associated with CRE research involved systematic data collection and data analysis, including representation, visualization, and interpretation. Depending on how each teacher implemented project work into the course, there was potential for students to develop computer models to test their hypotheses about patterns seen in the data and employ data-based reasoning to examine and justify their claims. The year-end symposia provided a forum where students could construct and present their explanations for conditions in the CRE and argue the strengths and weaknesses of various claims.



For students at each school, being engaged in data analysis involved learning *how* to organize data and look for patterns as well as *making sense* of specific aspects of the CRE ecosystem, through looking at the patterns in the data to explain conditions in the water (data-based reasoning). The results of the knowledge assessment questions related to students' understanding of and experience with these scientific practices indicate modest, yet significant gains, with each school's mean percentage of correct answers to questions in this category being higher on the post-assessment (by 10–30 percentage points) after participating in the CRESCENDO activities in 2018 (**Figure 3**). These gains were particularly evident in response to questions related to data collection strategies and techniques, how plankton abundance and composition can be used to make predictions about estuarine health, and how to visualize and utilize data to identify patterns of change over time and space.

In the group interviews, the student discourse made clear that many of them had opportunities to work with their CRESCENDO data in class, as several talked about modeling and made connections of their CRE data to other class projects focused on fish migration and wood duck habitats. Students at one school provided details on how they created graphs in MS Excel to display and organize their data:

Devin: “Yeah, we had a (CRESCENDO) project where every time we went, we constructed graphs for each different thing, such as nitrates or pH. And they were just lined up *via* month. And we also had the data from the other class periods to work with as well.”

Interviewer: “The other classes here?”

Devin: “Yeah and we compared our graphs to each graph actually. So that, oh this one (referring to a printed graph created by students). . . I think a lot of it was when the depth went down, certain other things also went down. . . Some things were rushed out of the river, I guess.”

Brooklyn: “So it was just like an analysis of what we were seeing in the data that we collected.” — Devin and Brooklyn, Northwest HS.

Students at this school were also supported in developing computer models to better understand relationships between water quality parameters and make predictions about changes due to changing conditions over time.

Robin: “The product we will be starting soon is, each student will be creating a model of comparing one factor to another. For example, my own is the level of phosphates compared to the amount of agricultural land in that area. . .”

Shane: “We’re using a program called Vensim, where basically, it creates models and you can apply one factor as well as an end result and things that affect each of those factors. Also, once you’re all done with that, it can also automatically create a graph of showing over time, this is what will happen.” — Robin and Shane, Northwest HS.

At Creek HS in 2017, students spoke about their desire to have data from the other participating schools so they could look for changes and commonalities in the various parameters at different locations upstream and downstream:

“Because I mean, we have our data, but there’s basically no data from other schools, to see how they’re doing, so we can’t really make correlations . . . because all we have is our data. So, if there was some sort of number string going on, I think that would help, so we can see how other places are doing. And then we can draw conclusions, well, fishing’s good down here, there’s no algae here, how is it up there, and vice versa.” — Bailey, Creek HS

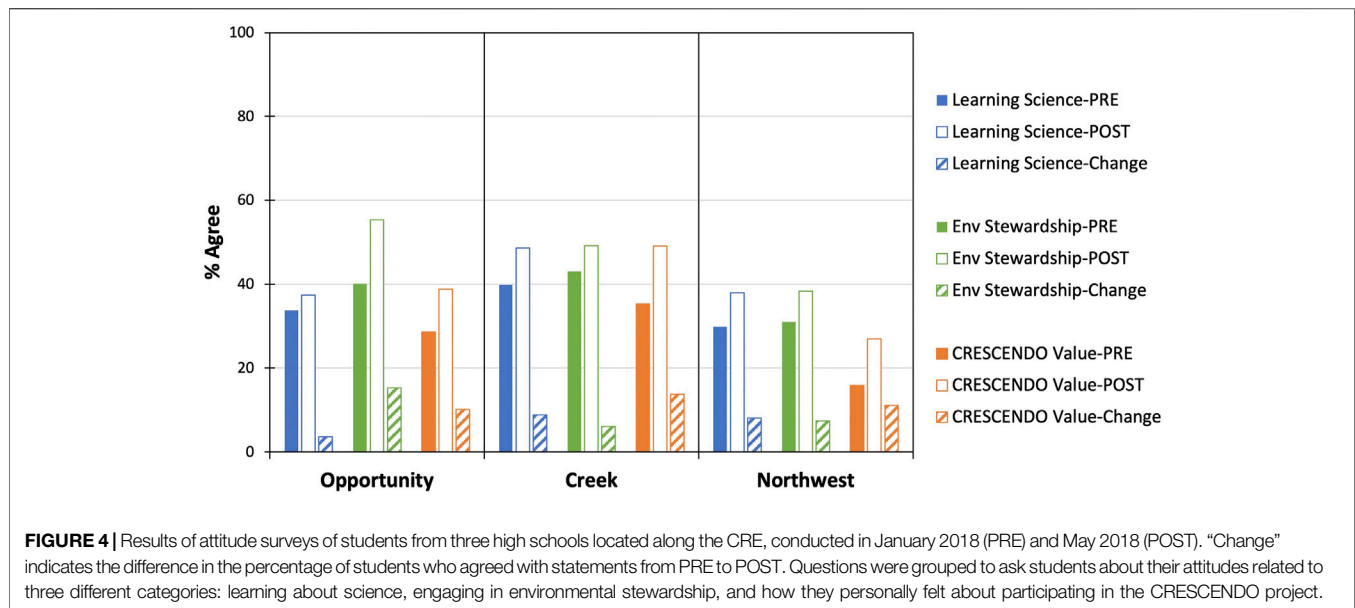
This improved in 2018, the second year of the project, as students were able to access data from all schools from the previous year. This provided them with a larger data set, which many desired in order to make sense of their local patterns and connect to land use and other events that could impact the water quality.

“We had a final analysis assignment where we did, in fact, compare last year’s results to our results in Vancouver. And then, we also compared everybody else’s results to Vancouver and why we think that, ‘Oh, why was the ammonia low this year?’ or something. Or ‘Why was blank this low this year?’ And we’d have to use outside environmental issues. ‘Oh, there was that big fire in the (Columbia River) Gorge. Did that affect it in any way?’” — Megan, Northwest HS.

The analysis of the CRE scientific data led some students to raise new questions, such as this Northwest student: “And I think one key thing that really came to me when I started looking at all the data, instead of just interpreting it and looking at the environment, which I’ve kind of done already. I think one thing is I kind of thought of when we kept seeing that construction being built with the port and everything, my thought was, ‘What about the water runoff? How was that going to contaminate the river?’”

### **RQ3: What Connections (if any) do Students Make Between Scientific Understanding and Environmental Stewardship? How Does this Impact Students’ Attitudes about stewardship of the CRE?**

The pre- and post-survey responses of students to statements related to their views about the environment and their personal connections to environmental stewardship demonstrated modest changes after participating in CRESCENDO activities in their classrooms. On average, in the pre-survey ~37% of students indicated that they engaged in activities and behaviors intended to improve environmental quality (e.g. recycling, invasive weed removal, etc.), which increased to ~48% in the post-survey (**Figure 4**). However, the increased agreement of



students with statements related to this topic were only statistically significantly higher at Creek HS.

Based on the results of the group interviews, it appeared that most of those students had an existing interest in environmental stewardship, often associated with activities they engaged in with family members or at school. However, the CRESCENDO project did provide an opportunity for students to make explicit connections between their activities and the health of the CRE, and also to learn more about local/regional community groups they could join in support of stewardship.

“Well, before I took the class, it was kind of like, yeah, I really wasn’t a big litterer or anything, but now that I’ve taken the class, it’s more of a big deal, I guess you’d say, just because I know what’s in the river and I know that if harmful stuff comes from the stuff that we’re putting into our river that is going to affect all the fish that we have and all the sea life.”—Gage, Creek HS.

“I mean, I enjoy science. I learn best with (my) hands . . . I love going outside . . . I thought it was very good at helping me learn on what is in our river, what we can do to help protect it, or at least try, all that.”—Jayden, Creek HS.

“I had a free elective, you know, it didn’t matter too much to me, so I thought I might as well try it (this class), and it’s definitely been a lot of fun . . . the water testing, the more environmental stuff is definitely something that I’d be interested in for maybe more like a hobby thing. Like an actual group . . . you know, like obviously, the peninsula doesn’t appear to have any major ones, but maybe wherever I live thirteen or whatever years from now, you know, if something like that’s around I’d definitely try to see what’s going on, learn about the environment where I live and seeing how I could help it.”—Ethan, Opportunity HS.

“I think one key thing that really came to me when I started looking at all the data . . . it’s like, how are we going to solve that problem? Because I know there’s a lot of contamination that comes when you have rain and then it hits the roof and then the rain goes into and picks up all this contamination and then brings it into the river, instead of going down into the soil and having the soil kind of filter out and then go into a river.” — Megan, Northwest HS.

#### RQ4: Which Aspects of the CRESCENDO Project are Perceived as Most Meaningful and/or Notable by the Students, and in What Ways do These Aspects Influence Students’ Interest in and Perceptions of Science, Scientists, and Scientific Work?

Student responses to survey statements about various aspects of the CRESCENDO project activities indicated a general increase in students’ personal appreciation for participating in CRESCENDO, as the mean level of agreement with such statements across all three schools increased from 26.6 to 38.3% pre-to post-survey (**Figure 4**), although the increase was only statistically significant among students at Creek HS. Similarly, students’ agreement with statements about the benefits of learning science through participation in an authentic university-sponsored scientific research project also increased pre-to post-survey from 34.5 to 41.3% (**Figure 4**), and were statistically significantly higher for students at both Creek and Northwest high schools. The greatest increases in levels of agreement (pre- to post-survey) were for statements such as:

- “Much of what I learn about the CRE is useful in my life.” (43–79%)
- “I like learning about the ecology of the CRE.” (49–76%)

- “I am more interested in studying science due to my participation in studying the ecology of the CRE.” (30–60%)
- “A job as a scientist would be interesting.” (55–80%).

Where students did show the most energy and enthusiasm for participating in the CRESCENDO project was in relation to engaging in outdoor field work and contributing to a university-level research project. Indeed, the highest number of individually coded responses (115) over six interview sessions were recorded in relation to this research question. The most common themes among these responses were:

- 1) Participating in CRESCENDO inspired students’ interest in and learning of science.

“...and then when we started CRESCENDO and going outside and doing things I’m like, “I think I could really do this. I could do this for a long time, and do this as a career, and I’d be okay.”—Olivia, Opportunity HS.

“When you’re doing it for fun, you’re like, oh, no big deal, I missed a step, but with actual science, you’re like, oh, cool, I feel like I’m an actual scientist; I don’t feel like I’m in high school; I feel like I’m out, I’m a grad student, I’m an actual scientist doing something that’s going to help.”—Bailey, Creek HS.

- 2) CRESCENDO allowed them to produce new knowledge that was personally useful.

“Previously with science class, I was just like, ‘Oh, it’s just science class, I’ll learn how to do stuff I won’t use in the future.’ However, with this, these projects and such, I find that there are real effects of things like chemistry in the environment that one could easily use in the future and so I feel like there’s real life benefits to learning these kind of things, the value of contributing to a project with a scope bigger than just their own classroom or school, and the opportunity to simply go outside.”—Shane, Northwest HS.

“It was cool just to get out and actually learn more about what’s in the water, what affects the water, about our tidal influence. Before this class I thought I knew stuff about it, but I really didn’t. I feel like I know a lot more.”—Gage, Creek HS.

- 3) Contributing to a project with a scope bigger than just their own classroom or school was valuable.

Interviewer: “All right. And then with the presentation that the WSU scientists made. How did that make you feel? Seeing all the data?”

Chris: “I thought it was pretty cool. Seeing our actual data state-wide ... on an actual college presentation. I thought that was pretty cool. Because like all these other big scientists are going to see the work that we did from

our small little school that nobody notices really.”—Chris, Opportunity HS.

“I’m thinking like, I definitely want this to be a project that continues. I feel like it’s pretty worth it, especially once we do connect with the schools and stuff like that, and if there’s ever a time where we’re able to see another school’s data compared to our data down the river, and be able to see ours over time. And I feel like that would be a really awesome experience for people to see they did something. And that it is through the university, I feel like it’s a really cool experience ... it’s a cool outreach as well.”—Liam, Opportunity HS.

- 4) Going outside was exciting, challenging and engaging (a theme that emerged in every interview and expressed at least once by each student).

“Science and everything, it’s a lot more than just paperwork and being in a lab the whole time. There’s actually science where you can go outside and participate in.”—Chris, Opportunity HS.

“So, this is my first year in environmental science. In my previous years, I’ve took physical science and stuff, but I personally think that this class is way better than all these other science classes. Because, like I said, I learn way better hands-on; I think it’s just way more fun going outside instead of sitting in a class and learning out of a book. Like, we actually get to go learn, do our hands-on. I just think that’s so much better.”—Logan, Creek HS.

Dana: “This project has been really fun. I really enjoy going outside regularly. It’s really something nice to look forward to, and it’s not something you’re likely to forget because ...”

Robin: “Except for when it’s raining.”

Dana: “Except for when it’s raining but it’s still fun. It’s still entertaining and it’s still like, ‘We’re going to go outside!’”—Dana and Robin, Northwest HS.

## DISCUSSION

Overall, students who participated in the CRESCENDO project made significant gains in their ecological knowledge of the CRE as well as in their understanding of scientific inquiry practices. They also made thoughtful and at times impassioned statements during small group interviews that indicated a deeper understanding of the connections between local land use and human behaviors and water quality in the CRE, as well as the dynamic nature of how nutrient concentrations could vary seasonally and along the axis of the estuary as water flows downstream to the ocean. While our student sample size was modest (128 unique pre-post assessment and survey respondents; 24 students in the focus group interviews), we believe these results indicate the potential for partnership programs such as CRESCENDO to measurably and positively impact student learning gains in science content.

It was also clear that the increased awareness and understanding of the ecology of the CRE that came about from participating in CRESCENDO made strong impressions on many students. This was evidenced in their ideas and discourse during the focus group interviews, even though we observed only marginally increased agreement with statements about the personal value of taking part in stewardship activities across the entire population of students in the CRESCENDO project. The most animated conversations in the interviews occurred when students were sharing their enthusiasm for taking part in a “real” scientific research project, collecting samples and making measurements in the same way as university scientists, and contributing “their” data to a larger investigative effort that extended beyond their own classroom and school. Students talked about developing a sense of ownership of and responsibility for the data they generated, and sometimes chided each other to be more careful with the equipment and samples when out in the field each month. Students also expressed a very strong level of enjoyment about having the chance to get outdoors during science class, and to put what they were learning into practice in a meaningful way (even though a few students admitted that going outside was the main reason they wanted to continue their participation in the project).

Our results align with and support previous research that shows that learning can be more meaningful when students engage in place-based and project-based science that allow them to apply scientific concepts in a real-world setting (e.g. Manzanal et al., 1999; Flanagan et al., 2019; Cho et al., 2021). Such experiences, especially in the context of environmental science education, can be transformative for students and may result in longer-term outcomes for environmental conservation and restoration (Ballard et al., 2017).

For instance, Bang and Marin (2015) discuss the critical role of science education in building students’ experience of and appreciation for the relations between the natural world and the social world (“nature-culture” relations), especially when students are given the opportunity to become deeply involved in exploring the connections between natural science (e.g. studying microbial life or monarch butterflies) and societal issues (e.g. human health or agriculture adaptations and food security). Investigations that result in data and observations that challenge a student’s unconscious and/or unquestioned cognitive assumptions about how the natural world works, referred to by Biggs et al. (2011) as their “mental model,” may lead them to subtly or substantially modify their conceptions of the environment around them. Biggs et al. (2011) posit that it is often the unrecognized differences in scientists’ and other stakeholders’ mental models about the environment that lead to challenges and/or failures of conservation planning efforts, and therefore suggest that such efforts are more likely to be successful when individuals understand and acknowledge the knowledge sources and assumptions that underlie their models. If students are guided and encouraged to examine their understanding of the natural world while they are young, this is likely to have

far-reaching implications for the choices they make and the activities they engage in further along in life (McFarland and Thomas, 2006).

An interesting, and somewhat unexpected, pattern we observed was the substantial difference in scientific inquiry and ecological knowledge gain among students at Creek HS compared to Opportunity and Northwest. While the teachers at each high school integrated the CRESCENDO project into different class types and content areas (e.g. Chemistry, Natural Resources, Environmental Science), our classroom observations, interviews with teachers and students, and examination of student demographic data did not reveal substantive differences in pedagogy or past student achievement that would explain these differences. In our view, the most likely explanation for higher knowledge gain of students at Creek HS was the fact that their Natural Resources class included active participation in several other place-based conservation projects in addition to CRESCENDO. The ecological and scientific inquiry concepts we assessed were likely synergistically reinforced for students in these other projects, resulting in enhanced learning and/or retention of this content—and if so, provides further evidence of the potential for active engagement in place-based scientific inquiry to advance student knowledge (van der Hoeven Kraft et al., 2011; Semken et al., 2017).

University-school partnerships in STEM engagement and learning are not new, and at least two other STEM-focused, place-based partnerships have resulted in gains in students’ scientific knowledge and science identities, although both of relatively short duration. During a week-long research experience in Prospect Park (Brooklyn, NY, United States), a group of 22 high school students mostly from groups historically under-represented in STEM worked with faculty from Brooklyn College to investigate two research themes (soil compaction and harmful algal blooms) that had been previously identified by students as important issues to address. Students’ science identities were positively impacted as a result of the program, as was their level of engagement in science activities (DeFelice et al., 2014). Similarly, after participating in a two- to 4-week Summer Science Academy research experience co-sponsored by the University of Rochester (NY, United States) and local Rochester schools, students from multiple K-12 grade levels self-reported significantly positive impacts of the program on their later academic success, interest in science, and likelihood to pursue a science-related career (Markowitz, 2004).

To our knowledge the CRESCENDO program was unique by having the partnership between Washington State University faculty and high school teachers from five regional school districts extend over two+ years, allowing for consistent and sustained involvement of students in university-sponsored ecological research that was specific to their own place. Moreover, the teachers engaged one (and in some cases two) of their entire class(es) of students over a full academic year. Our results suggest that this level of involvement contributed to the significant impact on both attitudes about science and gains in scientific knowledge that we measured, and also allowed for engagement of students



from both urban and rural schools who might not otherwise have had access to such experiences.

## Transferability and Opportunities for Future Implementation

We identified five elements of the CRESCENDO program that we believe contributed most to its success, and that we believe allow for effective transferability of this university-high school partnership model for advancing STEM learning across a range of contexts.

**Key Element #1:** Prior to the start of student involvement, the high school teachers were meaningfully engaged in developing the integration of the scientific research into their curricula, and received modest stipends for their commitment of effort and expertise to the project.

**Key Element #2:** Students were the primary field team members for a scientific study led by university researchers that extended beyond their own school, and therefore exhibited heightened attention to maintaining protocols for proper sample collection and handling, and developed strong ownership of their results.

**Key Element #3:** The sustained involvement in the project over an entire academic year allowed each cohort of students to observe seasonal changes in their local environment, as well as between their location and other sites along the CRE, which increased the opportunities to make meaning of their results.

**Key Element #4:** Students valued the opportunity to directly interact and collaborate with university scientists, both in their schools and on the university campus.

**Key Element #5:** The scientific research questions were explicitly devised to serve the dual purposes of advancing the on-going research programs of the university scientists, as well as providing meaningful education and outreach to high school students in one of the university's main undergraduate recruiting regions.

We acknowledge that the CRESCENDO model for a university-high school partnership requires the investment of resources from both partnering institutions, including faculty and teacher time, financial support for the initial purchase of equipment and/or supplies for student field efforts, and administrative “buy in.” However, our experience demonstrated the particular importance of Key Element #5 to the success and sustainability of the CRESCENDO model, namely the opportunity to leverage institutional resources toward a partnership that simultaneously advanced the research, education, and outreach missions of the university. We were able to utilize research funds (both external and institutional) for the “start-up” costs of the project, since the field work was incorporated into a larger, on-going faculty research program. The high schools also contributed resources to support substitutes for teachers to attend workshops, and in some cases buses/vans to transport students to the sampling sites. The project also provided a unique and rewarding opportunity for both teacher and faculty professional development, which contributed to their career advancement. For these reasons,

we strongly believe the CRESCENDO model of engaging high school teachers and students into on-going university-sponsored scientific research over periods extending from weeks to months (and possibly multiple years) can be effectively adopted by universities and high schools across a range of size, location, and institutional mission.

In summary, the gains in students' scientific knowledge and shifts in their appreciation for environmental stewardship resulting from participation in authentic and locally-relevant environmental research confirms the critical role for university-high school partnerships such as CRESCENDO to advance STEM education. Moreover, this project provided more evidence in support of place-based approaches for student learning, and the importance of immersing students in their environments where they can study the natural world by asking relevant questions and generating novel data about the science topics that matter to them.

## DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Washington State University Institutional Review Board. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

## AUTHOR CONTRIBUTIONS

GR-B and TH developed the research questions addressed in this article and conducted the qualitative analyses and interpretation of the students' responses during group interviews. GR-B conducted the quantitative analyses and interpretation of the students' responses to online surveys and assessments. JW developed the survey and assessment questions, and contributed to initial analysis of the student responses. GR-B wrote the manuscript, with significant contributions from TH. JW reviewed multiple versions of the manuscript.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fenvs.2021.797769/full#supplementary-material>

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