Engaging High School Students as Collaborators in Ecological Investigation of the Columbia River Estuary: Lessons from a Transdisciplinary University–High School Partnership

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Abstract

The Columbia River Estuary Science Education and Outreach (CRESCENDO) project was a university–high school partnership between Washington State University (WSU) researchers and science teachers and students from five high schools located in southwest Washington, adjacent to the Columbia River Estuary (CRE). The CRESCENDO project explicitly integrated ecological research with science education research that assessed how high school students' participation in university-sponsored research impacted their knowledge of CRE ecology and their attitudes about science and stewardship. From October 2016 to September 2018, CRESCENDO teachers and students measured water quality and conducted plankton tows from a dock near each of their schools every month. Each May, the CRESCENDO participants (WSU scientists, science educators, high school teachers, and students from each school) convened a Research Symposium to interpret the results. Here, we describe the project design and outcomes to illustrate the lessons learned from CRESCENDO and provide recommendations for developing future university–high school partnerships focused on locally relevant environmental problems.

Introduction

Addressing complicated environmental problems with the goal of producing sustainable ecosystems requires integrated and interdisciplinary collaboration among scientists, engineers, social scientists, educators, civil society actors, and citizens (Liu et al. 2007). Such a collaborative model exemplifies "transdisciplinary" research, in which collaborators from multiple disciplines both within and outside academia integrate their expertise to focus on shared problems, often with an action-oriented purpose (Lawrence and Després 2004; Brandt et al. 2013).

There is an acute need for transdisciplinary research focused on the sustainability of aquatic ecosystems, given the increasing threat from anthropogenic stressors acting at multiple scales. These stressors have especially strong effects on estuaries—ecosystems at the confluence of rivers and oceans, as well as the confluence of diverse human populations whose activities change watershed properties, increase the rates of eutrophication and introduction of aquatic invasive species, and may overutilize aquatic resources. Understanding the dynamics of nutrient concentrations and plankton populations in estuaries is therefore important to manage and steward these critical habitats (Collins et al. 2011).

Most transdisciplinary investigations into the interaction between human systems and environmental quality have focused on the impacts of governance structures, political decision making, and resource management (e.g., Chang et al. 2014; Mooney 2016). It is less common to include educational systems in such studies, despite K-12 education being a social system that substantially influences how young people develop knowledge, skills, attitudes, and behaviors that have impacts on their environment and generate feedback to management and stewardship of environmental resources (Gunckel et al. 2012).

Indeed, numerous studies in environmental education indicate that students' participation in local ecological or environmental studies have potential to change students' attitudes toward stewardship (Manzanal et al. 1999; Preston and Griffiths 2004; Gupta et al. 2012). Moreover, pedagogical research has demonstrated that learning can be more powerful when students engage in project-based science, where they apply scientific concepts and practices in a real-world situation (Manzanal et al. 1999; Kanter 2009), particularly when the projects relate to their own environment and their own lives (Banilower et al. 2010). This approach provides students with a framework for making sense of seemingly disparate facts and principles, as opposed to traditional science classroom activities where scientific practices and information are largely disconnected and prescribed (Donovan and Bransford 2005).

As university researchers in aquatic science and science education, with shared interests in environmental sustainability, we saw an opportunity to design and conduct a transdisciplinary research project that could contribute new knowledge about the role high school (HS) science education may play in connecting estuarine ecology with human activities in a watershed—focused around actively engaging HS students in university-sponsored scientific research.

With funding support from Washington Sea Grant, 1 of 33 National Sea Grant programs administered by the National Oceanic and Atmospheric Administration, we established the "Columbia River Estuary Science Education and Outreach" (CRESCENDO) project, a 2-yr university–HS partnership that integrated aquatic ecological research with science education research to investigate the interconnections of aquatic ecology, watershed land use, and social systems in the Columbia River Estuary (CRE), which extends 235 river km from the Bonneville Dam downstream to the Pacific Ocean and forms the western border between the states of Washington and Oregon (Fig. 1).

In this article, we share our CRESCENDO project design and implementation process and provide a set of recommendations for developing future university–HS partnerships that target environmental problems in aquatic systems. While working on the CRESCENDO project, we learned about the opportunities and challenges of transdisciplinary research, especially when establishing intentional and meaningful collaborations with HS teachers and students. As we describe below, we found the project to be extremely rewarding as researchers, and the students' enthusiasm for participating in scientific research about their local environment was energizing and contagious.

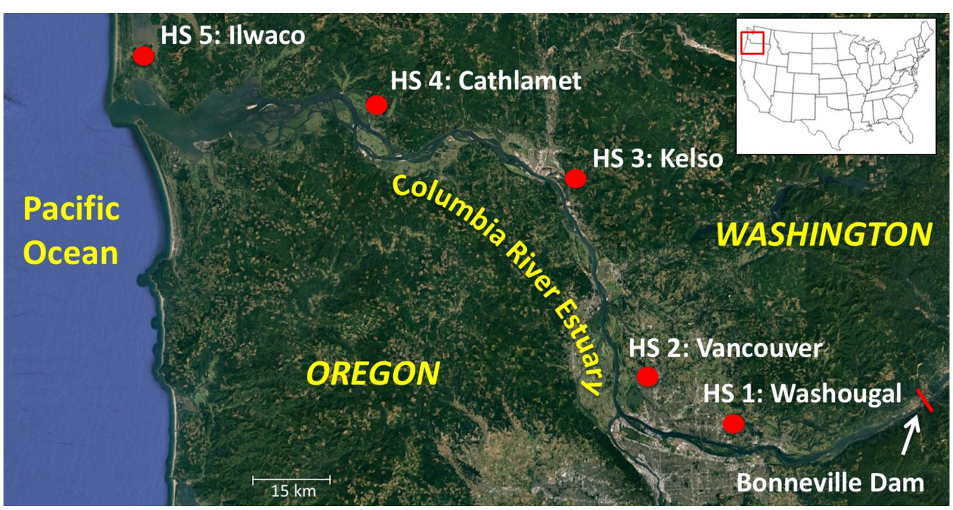

FIG. 1. Map of the CRE showing locations of five HS, where regular sampling was carried out by participating teachers and students. The CRE extends from the base of the Bonneville Dam (red bar on lower right) downstream to the mouth of the river at Ilwaco, Washington, and the Pacific Ocean (far left).

We hope our experiences will encourage other aquatic scientists to pursue similar transdisciplinary projects with colleagues in educational research. It is well worth the effort!

The CRESCENDO project

The CRESCENDO project was a partnership between aquatic science and science education faculty on the Vancouver, Washington, campus of Washington State University (WSU), and science teachers and their students from five public HSs located in southwest Washington and adjacent to the CRE (Fig. 1). Our goal in CRESCENDO was to engage HS students as full participants in our scientific inquiry focused on the ecology of the CRE, where the students worked alongside professional scientists to investigate their local environment as well as learn about the nature of science. At the same time, we investigated how such participation influenced the students' learning and attitudes toward science and environmental stewardship.

Conceptual framework and research questions: The foundation of scientific research about the natural world is the iterative process of scientific inquiry—questioning, observation and experimentation, analysis and interpretation, and communication with peers. Science educational research aims to understand how students learn scientific knowledge and skills, as well as how teachers most effectively engage students to achieve such learning. At the intersection of these two research cycles are the scientific practices themselves (Fig. 2). We used this conceptual model to frame our project and to explicitly link our two overarching research questions:

- What are the links among 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 HS students' understanding of CRE ecology, their participation in authentic scientific research, and their perceptions of and attitudes toward the CRE landscape?

Research rationale. We chose to focus on the CRE due to its significance to our region and because HS students living near the estuary were likely to have some degree of

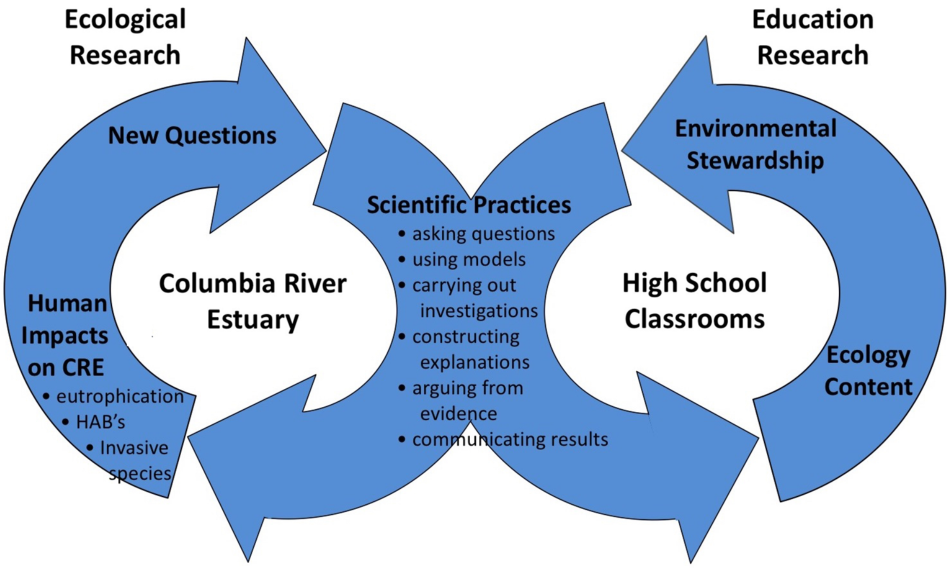

FIG. 2. Conceptual diagram illustrating the intersection between the processes of ecological research of the CRE and of HS science teaching and learning.

personal connection to this aquatic system, even if only indirectly. This estuary therefore provided an excellent environment around which to focus a transdisciplinary research project.

Specifically, the CRE is the largest river estuary on the U.S. west coast and is the dominant biophysical feature in southwest Washington (Fig. 1). The CRE is also the site of major shipping ports and associated infrastructure that support local economies, and the source of important commercial and recreational fisheries to the region. Recent population growth has led to large changes in land use within the lower Columbia River watershed, yet little is known about how this increased human activity and development may be impacting the ecology of the estuary, particularly the upstream–downstream transport of nutrients and plankton.

Nutrients and algal growth. Nitrogen and phosphorus concentrations in most estuaries are heavily influenced by anthropogenic sources such as agricultural fertilizers and/or wastewater treatment (Orive et al. 2012). In the CRE, coastal upwelling/downwelling combined with estuarine circulation can also be an important source (or sink) of nutrients, depending on the season (Whitney et al. 2005). Increased nutrient concentrations (i.e., eutrophication) can result in enhanced phytoplankton growth rates. Unfortunately, eutrophication in the CRE may be increasing the abundance of phytoplankton taxa that form harmful algal blooms (HABs). For example, cyanobacterial HABs are now known to regularly occur in Vancouver Lake (Lee et al. 2015; Rose et al. 2017; Rollwagen-Bollens et al. 2018), a shallow floodplain lake with tidal connectivity to the CRE, and are also becoming an increasing problem in the Willamette River, which flows into the CRE near Vancouver, Washington, and Portland, Oregon (Jacoby and Kann 2007).

Invasive zooplankton. Another environmental stressor acting in the CRE is the introduction and establishment of invasive zooplankton species (Bollens et al. 2012; Dexter et al. 2015, 2018), which have the potential to dramatically alter the overall planktonic food web by grazing upon phytoplankton taxa that may enhance HAB frequency (Bowen et al. 2015), as well as by displacing native zooplankton taxa that support critical fish and invertebrate populations in the CRE (e.g., salmon; Bollens et al. 2012; Adams et al. 2015).

CRESCENDO project design and implementation

The CRESCENDO project ran from August 2016 to September 2018, as a partnership between WSU Vancouver and five HSs located along the CRE in Washington state: Washougal High School (HS 1), iTech Preparatory High School in Vancouver (HS 2), Kelso High School (HS 3), Wahkiakum High School in Cathlamet (HS 4), and Ilwaco High School (HS 5) (Fig. 1). Over the course of two academic years, teachers from these schools engaged more than 300 HS students in the CRESCENDO project.

Recruitment and support for HS teacher participation. We identified one or a set of science teachers from each of five HSs that were approximately equidistantly spaced along the length of the CRE and also reflected a gradient in total enrollment, community type (e.g., rural and suburban), socioeconomic character, and surrounding land-use patterns. The teachers each received an annual stipend of $2000, and their schools received financial support for student transportation to their local dock. In addition, each school was provided with their own set of field sampling and analytical equipment that became permanent school property, including a plankton net, a handheld electronic temperature and salinity profiling instrument, water quality test kits, and a stereomicroscope with built-in video camera for observing plankton samples.

Prior to each school year, participating teachers attended a 1-d workshop on the WSU Vancouver campus, where they learned about CRE ecology and spent time at a local dock practicing use of the sampling equipment. Teachers also worked together to identify specific topics in their existing curricula to link to the CRESCENDO project and worked with WSU science education researchers to develop plans for implementing surveys and interviews of their students over the course of the coming academic year.

FIG. 3. Science teacher and students from iTech Preparatory High School conducting a plankton tow from a dock located in the main stem of the Columbia River near their school in Vancouver, Washington.

Estuarine sampling and analyses conducted by HS teachers and students. The CRESCENDO teachers and their students followed a strict set of protocols for when and how to conduct field sampling in the CRE, designed by the WSU scientists. Under the supervision of their teachers, students conducted plankton tows and vertical profiles of temperature and salinity and measured nutrient and dissolved oxygen concentrations from surface water samples collected from their dock each month during each academic year (Fig. 3). All data were recorded and shared with the other schools and with the university researchers. Two of the three replicate plankton net samples collected each month were sent to the WSU Vancouver Aquatic Ecology Laboratory for detailed, taxon-specific microscopical analyses required for scientific publication. WSU Vancouver scientists conducted all monthly sampling during summer.

Classroom observations, student surveys, and interviews. WSU Vancouver research faculty, graduate students, and research assistants visited each teacher's classroom at least twice per year to observe students in class and in the field. Participating HS students completed pre-academic and post-academic year surveys of estuarine ecology knowledge as well as their attitudes toward science and stewardship, and three to five student volunteers from each school participated in small group interviews with WSU Vancouver science education staff.

Annual CRESCENDO Research Symposia. At the end of each academic year, all CRESCENDO participants (including 5–30 HS students from each school) were invited to a Research Symposium on the WSU Vancouver campus. Students presented data and results from their CRE location to the rest of the participants, and then in small groups (facilitated by a WSU Vancouver Environmental Science graduate student), they examined subsets of the data (e.g., temperature, nutrients, or zooplankton composition) collected by all of the schools over the year to identify temporal and spatial patterns. Finally, the full group of CRESCENDO investigators developed a consensus of interpretations of each year's data.

CRESCENDO project results

We are now conducting detailed analyses of the nutrient and plankton data, as well as the student assessment and survey results, and preparing multiple manuscripts for submission to discipline-specific, peer-reviewed aquatic science and science education journals. However, several outcomes of the CRESCENDO project were quite evident by the end of the 2-yr field component with HS students and teachers, and we share these here as preface to our recommendations for designing similar projects in the future.

HS students increased their engagement in and enthusiasm for science and research. During classroom visits and the Research Symposia, the students were eager to talk about their field observations and how these compared to their own local knowledge of and experiences with the CRE and their surrounding community. Similarly, when students were engaging in data analysis, we observed students working to make sense of scientific data, as well as taking ownership of their work. We also observed that in the rural schools, where the local economy is driven in large part by natural resources (e.g., fishing, logging, and tourism), students made direct connections between their data and their own lives. In the higher enrollment suburban schools, embedded within large and diverse communities, where connections to the estuary are more diffuse, students expressed new curiosity about the CRE and an increased awareness of the estuary as an ecosystem and major feature in their environments that many had not considered before participating in CRESCENDO (T. Holmlund et al. unpubl.). Three direct quotes from HS students in the project illustrate this:

"I just thought: 'biology doesn't apply to what my future is because I plan on going into robotics,' but with the CRESCENDO project I see how my waste affects the world and how that can just generally apply to my own life."

"Well, it's gotten me more interested in what's in a river, and how does it work. Before I was like, I see the water, I know there's fish there, but now I see it as all different types of plankton and different pH, nitrates, and phosphorus. So now it makes me curious as to how it all comes together into the ecosystem."

"It was a fun project that was definitely unique and a lot of high school students probably don't get this experience. When you are out in the field you are doing what a scientist does and you are able to decide if you want to be a scientist in this area or volunteer time [outside of school]."

HS teachers engaged in scientific and educational research. Participating in the CRESCENDO project provided the teachers with a unique professional development opportunity related to estuarine ecology and allowed them to develop new professional networks with other regional science teachers and with university faculty (T. Holmlund et al. unpubl.).

University researchers learned the rewards and challenges of establishing a transdisciplinary research program. As faculty at a major land-grant university, we often engage with local and regional stakeholders or K-12 schools and teachers as part of our independent research. However, the CRESCENDO project provided an entirely new model for reciprocal interaction with HS teachers and students as collaborators in an externally funded scientific research project. This project was particularly impactful for the graduate students and undergraduate research assistants, who were entrained into transdisciplinary research in the early stages of their career development.

We have new insights into the distribution and abundance of critical HAB taxa and invasive zooplankton in the CRE. During CRESCENDO, we generated a large and unique dataset of quasi-synoptic monthly samples of water quality and plankton abundance along the full length of the CRE. We are now describing the seasonal and (to a lesser degree) the interannual patterns in the abundance and distribution of several critical planktonic taxa in relation to land use in the watershed, in particular the cyanobacterial genera *Dolicospermum*, *Aphanizomenon*, *Aphanocapsa*, and *Microcystis* (G. Rollwagen-Bollens et al. unpubl.) and the invasive copepod *Pseudodiaptomus forbesi* and cladoceran *Bosmina coregoni* (K. Connelly et al. unpubl.).

Recommendations for developing university–HS scientific and educational research partnerships

We intend to continue collaborating on similar research that integrates aquatic science and educational research questions and methodologies, and we highly recommend other investigative teams to consider developing such collaborative projects. As we all move forward in this area, we provide the following six recommendations for developing research partnerships among universities and HSs, based on what we learned in the CRESCENDO project.

1. ***Think locally yet also globally when choosing an environmental system to study.*** Identify a locally or regionally relevant problem or issue that uses methods accessible to young participants or that may be routinely supervised to ensure data quality. Important research questions can often be effectively addressed using well-established field and laboratory methods appropriate for the nonspecialist (e.g., HS students or other citizen scientists). Also consider local issues that can contribute to understanding broader themes that are of interest at larger scales. This will make a project much more fundable and more likely to produce results appropriate for publication in peer-reviewed journals.
2. ***Embrace projects that engage HS students in field-based research and then plan accordingly.***
   - *Expect the unexpected.* Field-based aquatic research will always be subject to the vagaries of weather, and we learned quickly that our normal protocols for worker safety in the field had to be expanded when working with youth, particularly in groups. Thus, in addition to designing strict protocols for sampling (e.g., sample on a Tuesday or Wednesday of the second week of each month and all students wear life jackets while on the dock) be sure to develop clear contingency plans for alternative sampling dates and sites for each location.
   - *Maintain continued training and oversight.* The CRESCENDO HS teachers participated in annual workshops to learn and practice the proper deployment and retrieval of field sampling equipment, processing of samples collected, and recording of measurements on data sheets. However, at times, the samples were collected by students using somewhat variable deployment methods, and observations were not always recorded properly (although they could usually be reconciled after the fact). Plan to retrain the teachers and students in field protocols at least twice during each academic year of a long-term project to ensure consistent methods and reliable data.
3. ***Engage early with potential collaborators and be inclusive during project design.*** We recommend engaging with HS teachers and principals early, and consistently, in the process of developing an integrated scientific and educational research project. These education professionals bring critical insights to the project design, as they know their students, their curriculum, and their school cultures in ways that complement the expertise of science education researchers. Although it is not a prerequisite for success, we also strongly recommend initiating a new transdisciplinary project with a small group (or even a pair) of researchers from aquatic science and science education disciplines who have already established some level of collaboration and professional interaction. We began the CRESCENDO project as a team of investigators with a long history of collaboration and with a group of highly skilled and enthusiastic teachers. Yet, it still took much longer than expected to develop and implement our partnership project due to the complicated logistics and multiple methodologies required. We benefited from having a good base from which to build, and ultimately, the rewards of conducting transdisciplinary research far outweighed the start-up challenges.
4. ***Plan for equity and diversity from the beginning.*** Partnerships among scientists, educators, school administrators, students, and other community stakeholders allow for targeted efforts to address locally relevant issues in a comprehensive and often creative manner. These partnerships should also intentionally include people with backgrounds and experiences that represent the diversity of the communities who are invested in these issues. One of the results of our CRESCENDO project was the stark difference in how students from rural and relatively economically disadvantaged schools connected their new ecological knowledge about the CRE to their role in sustaining this ecosystem compared to the responses of students from larger, suburban, and relatively well-resourced schools. The suburban students made connections that were more academic in nature and less related to their personal experiences compared to the students attending rural schools whose lives were more directly connected to the estuary. We would have likely missed this important difference if we had partnered only with schools located within commuting distance from the university or clustered in only one area of the estuary.
5. ***Build in flexibility for incorporating the scientific research into teachers' curricula.*** Public school science teachers act at the nexus of multiple and at times competing pressures from their local principals and school districts, their state-mandated and federally-mandated science standards, as well as the concerns and expectations of parents, students, and other community stakeholders. HS science teachers who are interested in participating in a university–school partnership are already likely to be in the position to incorporate new scientific research into their curricula. However, it is critical that teachers be allowed the flexibility in how they incorporate field sampling and data analysis components into their class schedules, while also accommodating their many constituents.

   For instance, we found that teachers of basic science classes where the content was highly prescribed (e.g., required courses such as biology or chemistry) connected their students to the research in quite different ways than teachers of elective courses (e.g., natural resource science or marine biology). The monthly nitrate and phosphate concentration data, for instance, provided compelling opportunities to connect CRESCENDO activities to lessons about nutrient cycling and local land-use patterns in a natural resource science class, but it required a bit more creativity from the teacher of a standard chemistry class to incorporate this material. Therefore, any partnership between scientific researchers and HS teachers needs to be flexible enough to accommodate the unique characteristics of each classroom and institution without jeopardizing the ability to conduct a research project that will produce robust and scientifically defensible results.

6. ***Maximize the opportunities for interactions between university scientists and HS students—this is the fun part!*** For us, one of the many highlights of the CRESCENDO program was engaging in meaningful classroom discussions with HS students about their observations and experiences working in and around the CRE. In the smaller rural schools located in communities with strong associations with the estuary, the students' enthusiasm was contagious when describing how their lives and those of their family members were connected to the water and the surrounding watershed. They clearly appreciated learning about the ways in which human activity, both locally and further upstream, could be influencing the health of "their" estuary. In the larger suburban schools, it was incredibly rewarding to hear the excitement from students who ventured out onto a floating dock and for the first time actually touched water from the CRE—an entirely different experience of the river estuary than viewing it from the window of a car while crossing the interstate bridge.

   At all of our partner schools, the teachers reported high anticipation among their students for the visits by university scientists, as it symbolized our recognition and appreciation for their contributions to conduct authentic scientific research. This turned out to be the best part of the CRESCENDO project for us as well.

Concluding remarks

In this 2-yr project, we set out to combine scientific and educational research approaches to better understand how upstream–downstream dynamics and land-use patterns in the watershed influence the ecology of the CRE and to understand the influence of students' participation in scientific research on their attitudes toward science and environmental stewardship. In the process, we learned a great deal about nutrients, phytoplankton, and zooplankton dynamics in the CRE, and about the value of and challenges to including HS students and teachers in field research.

As university faculty accustomed to conducting and publishing research that is nationally and internationally recognized in our respective disciplines, we found the experience of intentionally developing and implementing an integrated, regionally-focused, transdisciplinary project to be refreshing, intellectually invigorating, and at times daunting. Collaborating across disciplines, university administrative units, and institutions with disparate missions and stakeholders requires patience, flexibility, creativity, and a willingness to take professional risks. Such work is time consuming, as all parties learn each other's practices and expectations, and the group explores avenues of investigation that result in unexpected outcomes that must be reconsidered. However, in the CRESCENDO project, we observed exciting changes in how young students understand and experience their environment and their place in it, and the results of our investigation will contribute not only to our traditional disciplines but also to the emerging practice of transdisciplinary research.

Author Contributions

G.R.B was the Project Director for CRESCENDO, and wrote the manuscript. T.H. and S.B. were co-PIs on the project, contributed to project design and data collection, and edited the manuscript. J.Z, K.C., and L.B. participated in school visits, data collection, and analyses, and edited the manuscript.

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