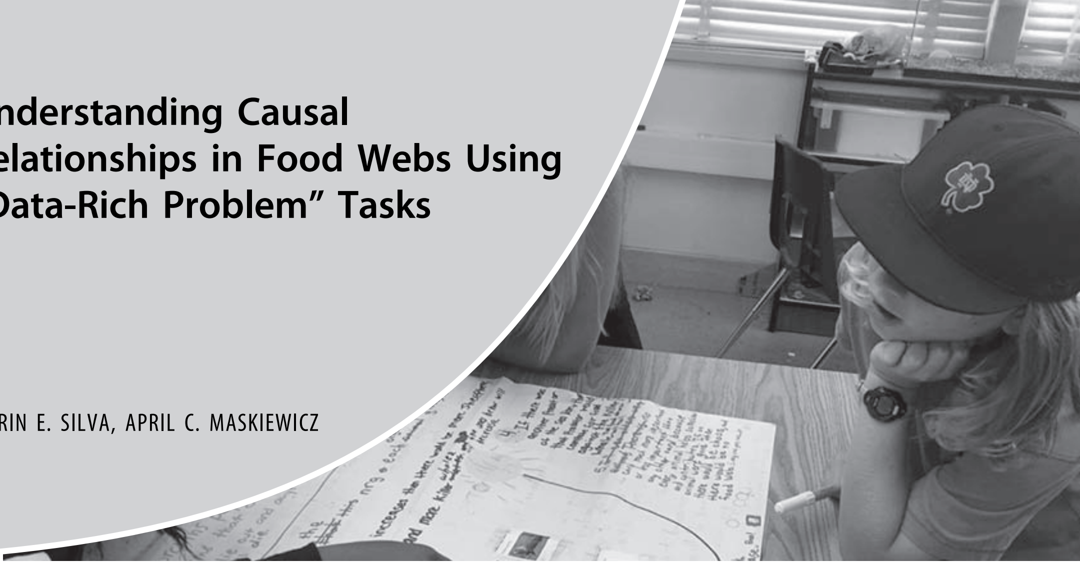
FEATURE ARTICLE

Understanding Causal Relationships in Food Webs Using "Data-Rich Problem" Tasks



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Abstract

We used a design-based research approach to develop "data-rich problem" (DRP) tasks intended to support middle and high school students in constructing knowledge about food webs and ecosystem dynamics, specifically the effects of species loss. The marine environment is used for context to promote an understanding of interdependent ecological relationships and the nonlinear and sustaining effects of loss of species. The Food Web DRP tasks we describe are designed for classroom implementation in alignment with the Next Generation Science Standards. The intended time frame for implementation is five days (assuming 50-minute class periods).

Key Words: *Ecosystems; food web; nonlinear relationships; systemic relationships; Next Generation Science Standards; data-rich problem tasks.*

○ Introduction

Student understandings of any topic should seemingly tend to increase as a student progresses through school; however, student understanding of ecological relationships and the functioning of ecosystems doesn't appear to meet this expectation. Studies have revealed a pattern in student understanding, beginning before high school (Hogan, 2000; Grotzer & Basca, 2003) and extending through high school (Griffiths & Grant, 1985; Webb & Boltt, 1990; Barman et al., 1995) and into college (Webb & Boltt, 1990; White, 2000), in which students continue to view the complex relationships within food webs as linear instead of cyclical or systemic. As a result, students are not fully equipped to be responsible citizens in their local communities, where the effects of human disturbance and loss of species are occurring. To fully grasp the depth of how an ecosystem is affected by various interactions (e.g., human disturbance, natural disaster, fire), students must understand the complexity of the relationships within an ecosystem's food web and "recognize all possible pathways through which the effect of a change in one population is transmitted to a second population" (Griffiths & Grant, 1985, p. 434). In other words, we need to help students view food webs as dynamic systems instead of seeing species interactions only as direct cause-and-effect relationships.

As a result, students are not fully equipped to be responsible citizens in their local communities, where the effects of human disturbance and loss of species are occurring.

Here, we introduce a set of "data-rich problem" (DRP) tasks that use the marine environment as context to help middle and high school students understand interdependent ecological relationships and the nonlinear and sustaining effects of species loss. The *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013) state that students must be able to "construct arguments supported by empirical evidence, construct explanations that predict patterns, and support and revise explanations based on evidence" (NGSS Standard MS-LS2-4, MS-LS2-2, and HS-LS2-2). When two classes of seventh-graders engaged with these tasks, we found that most students began to "recognize patterns in data and make warranted inferences about changes in populations, and evaluate empirical evidence supporting arguments about changes to ecosystems" (NGSS Standard MS-LS2-4).

○ A Design-Based Approach to Concept Refinement of Causal Relationship in Food Webs

According to studies in the learning sciences, a successfully designed teaching intervention should include the student as an active participant in the learning process. The three steps of the "Learning-for-Use" framework (motivate, construct, and

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refine) represent one such approach, integrating both content and process learning (Edelson, 2001). Edelson et al. (2002) propose that modules incorporating these three steps allow students to "construct new understanding that more closely resembles scientific understanding" (p. 19). White and Maskiewicz's (2014) DRP tasks for understanding ecological processes (i.e., cellular respiration) demonstrate how the Learning-for-Use framework can be used successfully. In high school classes where their DRP tasks were utilized, White and Maskiewicz (2014) found significant gains in student reasoning of ecological processes, including some students showing high levels of complex and scientific reasoning.

For the present study, we used the Learning-for-Use framework to design Food Web DRP tasks intended to increase student understanding of the dynamic and complex relationships within ecosystems. The Food Web DRP tasks begin by trying to create some cognitive dissonance (motivate), followed by the students analyzing data to support knowledge construction (construct), and finally applying their knowledge to new scenarios and more complex relationships (refinement). These tasks were designed on the basis of student interview data, followed by two iterations of implementation and task refinement (Collins et al., 2004).

○ DRP Task Implementation

The Food Web DRP tasks can be found at https://sites.google.com/site/marineecosystemdrptasks/. These problem tasks were originally developed for middle school students, but the tasks are appropriate for high school students as well. The high school standards include specific language about the "use of mathematical representations" (HS-LS2-1 and HS-LS2-2). Given that the data in these tasks are provided, high school instructors can modify these tasks to focus more on mathematical representations instead of focusing only on the overarching trends of the populations. (For objectives and alignment with middle and high school standards, see Table 1.)

The Food Web DRP tasks address other dimensions of the NGSS standards in addition to those listed in Table 1. As students work in teams drawing food webs and predicting changes to populations, they are also engaging in additional practices such as model building, argumentation, and communication. Finally, the tasks touch upon several NGSS crosscutting concepts including patterns, systems thinking, energy and matter, and stability and change.

The tasks are designed for students to work in teams of four, over a five-day period (~50 minutes a day). Each group will complete each task by examining contextualized data provided to them,

Table 1. Connection to the *Next Generation Science Standards* for each implemented task (MS = middle school, HS = high school).

Tasks	Performance Expectations, Science and Engineering Practices (SEP), and Crosscutting Concepts (CCC)
Food Chain Comparison	CCC: Patterns – Patterns can be used to identify cause-and-effect relationships
Food Web Construction	SEP: Developing and Using Models CCC: Cause and Effect
Top-Down DRP	MS-LS2-1 MS-LS2-2 HS-LS2-1 HS-LS2-2 SEP: Analyzing and Interpreting Data (MS); Engaging in Argument from Evidence (MS and HS); Using Mathematics and Computational Thinking (HS) CCC: Cause and Effect (MS); Scale, Proportion, and Quantity (HS)
Mid-Level DRP	MS-LS2-1 MS-LS2-2 HS-LS2-1 HS-LS2-2 SEP: Analyzing and Interpreting Data (MS); Engaging in Argument from Evidence (MS and HS); Using Mathematics and Computational Thinking (HS) CCC: Cause and Effect (MS); Scale, Proportion, and Quantity (HS)
Food Web DRP	MS-LS2-1 MS-LS2-2 MS-LS2-4 HS-LS2-1 HS-LS2-2 HS-LS2-6 SEP: Analyzing and Interpreting Data (MS); Engaging in Argument from Evidence (MS and HS); Using Mathematics and Computational Thinking (HS) CCC: Stability and Change (MS and HS); Scale, Proportion, and Quantity (HS)

make predictions, and record answers to guiding questions on poster paper (which will later be shared with the whole class). During our implementations, we found that when teams worked individually, without whole-class discussion, scientific explanations were not always the outcome. But when the work in teams was followed by whole-class discussion, students often came to a consensus aligned with scientific explanations.

In the classroom-implementation information that follows, specific details are provided on how to facilitate each task. These suggestions are based on empirical data gathered from various iterations of the design process (Silva, 2015), and we found this pedagogical approach most effective. Table 1 shows the learning goals for each task.

Day 1: Food Chain Comparison (~50 minutes)

Each team receives a laminated diagram of three food chains (which are part of a larger food web) and a set of questions. The arrows that connect the organisms in each chain are labeled with the approximate energy units per gram that are transferred from one trophic level to another. Teams first complete a T-chart of similarities and differences among the three food chains. Upon completion, a "similarities and differences" list can be generated on the board for the class to see and discuss. Student answers for the follow-up questions should also be discussed. It is important to use questioning strategies to highlight student ideas that demonstrate connections between the food chains instead of merely discussing them as individual food chains. For example, question 6 specifically asks students if a change in a population in one food chain can affect a population in another, while questions 7 and 8 ask about changes to the ecosystem. Students should be encouraged to explain the effects on the entire ecosystem, not just the effects on populations within an individual food chain.

Day 2: Food Web Construction (~50 minutes)

Each team is given a set of laminated organism cards (Figure 1) and the follow-up questions. Students are (1) told that the cards represent different populations of organisms that make up a food web in a marine ecosystem and (2) instructed to arrange the organism cards to create a food web, which will eventually be drawn on poster paper. Students then rotate to each group to view the food webs that other teams constructed, which is followed by a brief class discussion to identify similarities and differences among the various posters.

The intent of this task is for students to notice that some groups drew arrows pointing in the direction of energy flow while others drew arrows pointing in the opposite direction — representing "who eats whom." The instructor may need to guide students to compare the previous task's arrows to the arrows in this task and future tasks. Within an ecology unit or a matter and energy unit, the distinction of what the arrows represent could be highlighted (matter and energy flow). Together, the class should create a "final" food web to be projected on the board before moving on to the team questions. More discussion will continue on Day 3.

Day 3: Class Discussion & Top-Down DRP Task (~50 minutes)

Students should first review the answers from Day 2. If time permits, students could turn to other students in different teams to share, discuss, and argue the ideas. Task 2 is not complete until the answers to the questions are reviewed in a whole-class discussion, because this is where refinement of scientific ideas occurs. Questions 4 through 7 ask how a disturbance will influence the ecosystem, and again the instructor should encourage students to describe how this disturbance will affect the entire ecosystem, not just the species directly connected to where the disturbance occurred.

Task 3 should be completed as a whole class so that the instructor can model the expectations for how to navigate the data tables and the questions about organism relationships. Provide a copy of the questions, the food chain, and the data table to each student and have teams answer the questions one at a time on their poster, with class discussion in between each question. Some students rely strictly on the data to explain their answers, without also describing the relationships between the organisms. For example, they may notice that the sea otter numbers are increasing, and they will propose values that continue that trend without describing how this is possible. While the exact values are not important, we believe it is important for students to hypothesize actual values instead of simply stating "decreasing" or "increasing." By providing specific values, the student is considering the relative magnitude of the change while generating connections between different trophic levels. For example, a change of five organisms at the producer level is not nearly as significant as a change of five organisms at the level of tertiary consumer. Figure 2 shows the data table used in this task. It is important to note that sometimes students will ignore the context or scenario and only utilize the data to predict or explain population numbers. For example, even in Task 3 the scenario is a top-down disturbance, yet students may explain that the urchin population is increasing because the kelp population is increasing. This separation of data from context is a common student error to watch for in all subsequent tasks.

During this lesson and over the next two days, the instructor will need to continually remind students to focus on the scenario that is driving the changes to the ecosystem, because it is common for students to focus only on the values in the table and, thus, make incorrect conclusions. Also, depending on how comfortable they are in using evidence to support a claim, the students may need reminders that their answers must be grounded in the data and the relationships provided in the food web – instead of using their own background knowledge from observations outside of class (e.g., "I saw a killer whale eat fish on a TV show, so I know they can eat other stuff"). While making connections to their life outside of school is important when learning, students also need to learn that claims without specific evidence are actually hypotheses and not conclusions.

Day 4: Mid-Level DRP Task (~50 minutes)

This task also involves human-induced loss. Though we recognize that there are many other kinds of disturbances in an ecosystem, we chose specific, human-induced scenarios so that middle school students can more easily relate to the scenario as a possibility. We recommend that the instructor discuss other types of disturbances, such as drought, flooding, and disease, during the implementation of this task.

To start this task, provide each student a laminated copy of the food chain with the data table and the follow-up questions. When

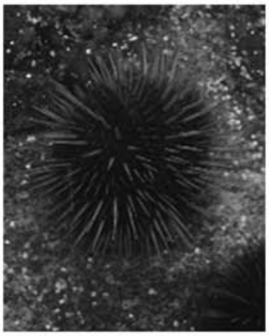
Giant Kelp –sea urchins eat this. 	**Sea Urchin** – Sea Otters and CA Sheephead eat this. 	**Sea Otter** – Killer Whales eat this. 
CA Sheephead – Sea lions eat this. 	**CA Mussel** – Sea Otters and the CA Sheephead eat this. 	**Killer Whale** – needs 240,271 units of energy per day. 
Steller's Sea Lion – Killer Whales eat this. 		

Figure 1. Organism cards for food web construction (reference for killer whale's energy needs: adapted from Williams et al., 2004).

teams have completed the questions, individual members from one team should be paired with members from other teams (one-on-one) to discuss their respective teams' conclusions. This promotes scientific argumentation, whereby students learn to defend and modify their ideas. We found that repeating this multiple times is productive and gives students the opportunity to bring new ideas back to their team to discuss and compare with their original ideas. A whole-class discussion should follow, to share any ideas that are

Kelp → Urchin → Sea Otter → Killer Whale

	Population Size Over Years				
Species	0 years	5 years	10 years	15 years	20 years
Kelp	124,000	Increase	213,000	Increase	332,000
Urchin	13,000	Decrease	Decrease	Decrease	Decrease
Sea Otter	124	Increase	279	336	Increase
Killer Whale	12	8	4	2	0

Figure 2. Data table for top-down DRP. Boxes are in gray for students to hypothesize values. Annotations of "increasing" and "decreasing" were added to show expected trends. Students should predict specific population numbers for each yellow box.

	Population size over years						
Species	0	5	10	15	20	25	30
Kelp	28,500,000	28,800,000	28,600,000	28,400,000	28,700,000	20,000,000	6,700,000
Urchin	4,670	4,400	4,780	4,500	4,200	6,600	14,500
Sea Otter	154,000	92,000	46,000	29,000	11,000	4,000	120
Killer Whale	170	172	171	173	172	168	169
Sea Lion	70,000	40,000	13,000	12,000	8,000	5,300	3,500
CA Sheephead	136,000	198,000	244,000	261,000	279,000	124,000	42,000
CA Mussel	1,800,000	1,840,000	1,830,000	1,860,000	1,850,000	2,340,000	4,800,000

Figure 3. Data table for Food Web DRP task. Years 0 through 20 are utilized for the first part of the task; years 25 to 30 are utilized for the second part. References: killer whale, sea lion, and sea otter population values (Williams et al., 2004); kelp population values (adapted from van Tamelen & Woodby, 2001).

still conflicting or unresolved, and to ensure that the scientific explanations have emerged.

Day 5: Food Web DRP Task (~50 minutes)

This task has two parts. The first includes a scenario in which a disturbance occurs in a population that is on the periphery of the food web. The population numbers for each species are provided over a 20-year time span. With such a large set of relationships and data, students will at times forget to consider that the population numbers are changing because of the scenario and will need continual reminders to consider the scenario as the driving force behind the changes. When the students have completed the questions, the collaborative process from Day 4 should be repeated, followed by a class discussion . Within this discussion, what it means for an ecosystem to "survive" should be highlighted. Students may think that if a few of the original species survive, the ecosystem has "survived." Students need to understand that the ecosystem has not "survived" if species have become extinct; instead, it has become a different ecosystem. This will be necessary for the second part of this task.

At the completion of the class discussion, the instructor introduces a new scenario and teams hypothesize about what will happen to the ecosystem over the next 10 years based on the data from the first part of the task. Figure 3 shows the data table used.

Before viewing the new data and answering the second question, students should have enough time to share their hypotheses with their teammates and between teams. The task is designed so that when teams have completed the last question, a class discussion should follow in which the students come to the conclusion that without regulation the ecosystem will collapse.

○ Exploratory Study of Task Effectiveness

In the winter of 2015, these Food Web DRP tasks were implemented in two seventh-grade classes (N = 55) in a diverse public school in southern California (46% of the students qualify for free or reduced-price lunch). As a result of that implementation and the data collected, another round of refinements were made to the tasks, and two of the tasks were omitted for the final version presented here. These deleted tasks were found to be redundant and did not seem to contribute to further knowledge construction. At the completion of the tasks, we assessed the students' knowledge and understanding of the interdependent relationships in food webs by using the Food Web Dynamics Assessment (see website for assessment instrument). The assessment included a modified version of the Food Web Relationships task developed by Webb and Boltt (1990) and a set of questions analogous to the DRP tasks but utilizing a unique ecosystem and food web.

The assessment targeted four main focus areas: linear vs. nonlinear reasoning, dissipation vs. persistence reasoning, understanding of food chains, and understanding of energy arrows (see Table 2). Some of the assessment questions targeted more than one focus area. Therefore, students' written responses were coded using a modified coding scheme from Dauer et al. (2013). Each student's codes for each focus area were totaled and divided by the total possible for that focus area (receiving a 3 on each question). The coding scheme and focus areas are described in Table 2, and the results for this exploratory implementation are graphed in Figure 4.

The assessment results indicate that most students performed at or above 60% for each category: linear vs. nonlinear = 61.1%; dissipation vs. persistence = 65.7%; food chains = 69.4%; and energy arrows = 92.6%. Students performed best on understanding the direction of the arrows in food webs, but this topic does not require extensive conceptual understanding. Reasoning about nonlinear relationships and persistence of a disturbance in an ecosystem are more complex and nuanced concepts to grasp (White, 2000). These conclusions, as well as the observational outcomes from implementation of the tasks in the classroom, supported the refinement of the final DRP tasks presented here.

○ Classroom Implications

The NGSS are described as moving away from what students "will know" to what students "can do" to demonstrate their knowledge. This move in student learning may address the challenge of how to help students think in terms of systems instead of linearly. The DRP tasks designed for this study incorporate the following NGSS crosscutting concepts that scientists utilize to understand science: patterns, cause and effect, system and system models, energy and matter, and stability and change. Using contextualized real-world data, the Learning-for-Use framework, and a design-based methodology, our work reveals that students are able to learn by first being motivated by a problem or scenario, then constructing their knowledge through the use of data, and finally refining their conceptions through activities that build upon the prior tasks. This type of learning environment allows students to

Table 2. Coding scheme and description of assessment focus areas, with assessment results (average for all students in each category). The total score possible for each category was calculated on the basis of receiving a "3" on each question within that category.

Code	0	1	2	3
Description	Missing; question was unanswered	"Unscientific," inappropriate	Marginally "scientific," ambiguous or poorly worded	As "scientific" as can be expected

Concept	Assessment Result
Linear vs. Nonlinear: *Linear* describes the incorrect idea that species interactions are limited to direct cause-and-effect relationships, as opposed to cyclical or systemic (*nonlinear*) relationships.	61.1%
Dissipation vs. Persistence: *Dissipation* describes the incorrect idea that the effects of a perturbation in one location in an ecosystem will weaken or dissipate as they spread through the ecosystem.	65.7%
Food Chain: *Food chain* describes the knowledge and ability to trace and describe the effects of a disturbance in a food chain.	69.4%
Energy Arrows: *Energy arrows* describe the knowledge that one organism in a food chain or food web "provides energy to" another organism, as opposed to consuming another organism.	92.6%

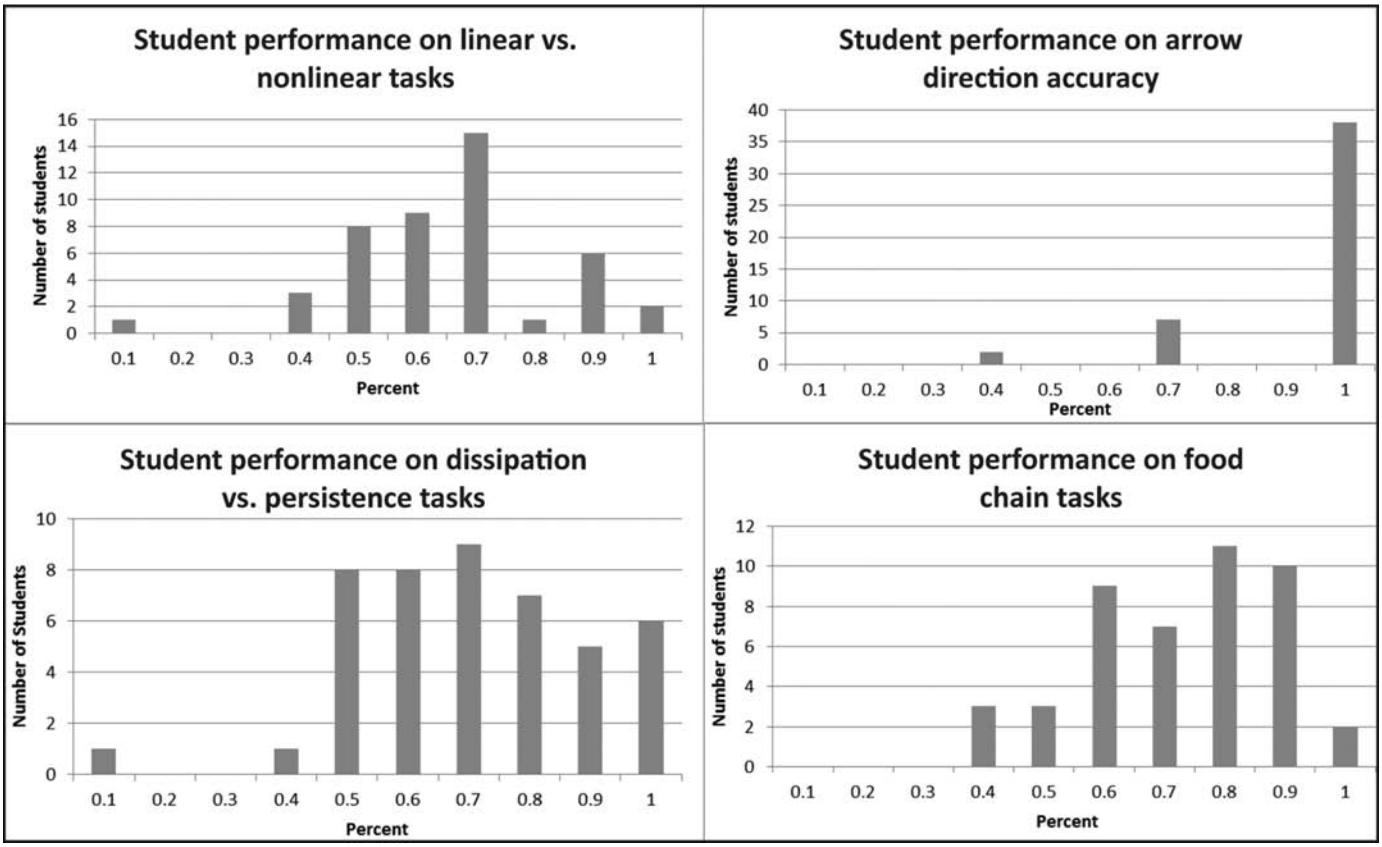


Figure 4. Student performance on four focus topics.

take an active role in their learning instead of passively listening (as is often the case with direct instruction).

If we continue to limit instruction in ecology to focus primarily on linear relationships, we cannot expect our students to become citizens who make informed and responsible decisions that could, in turn, affect Earth's ecosystems. Working through these Food Web DRP tasks, the students had opportunities to construct their scientific understandings about dynamic, cause-and-effect, cyclical relationships that exist in nature. At the seventh-grade level, these tasks have already proved to be a compelling intervention aligned with NGSS. It is with high hopes that research into the effectiveness of these DRP tasks continues, with other educator-researchers and at other grade levels.

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