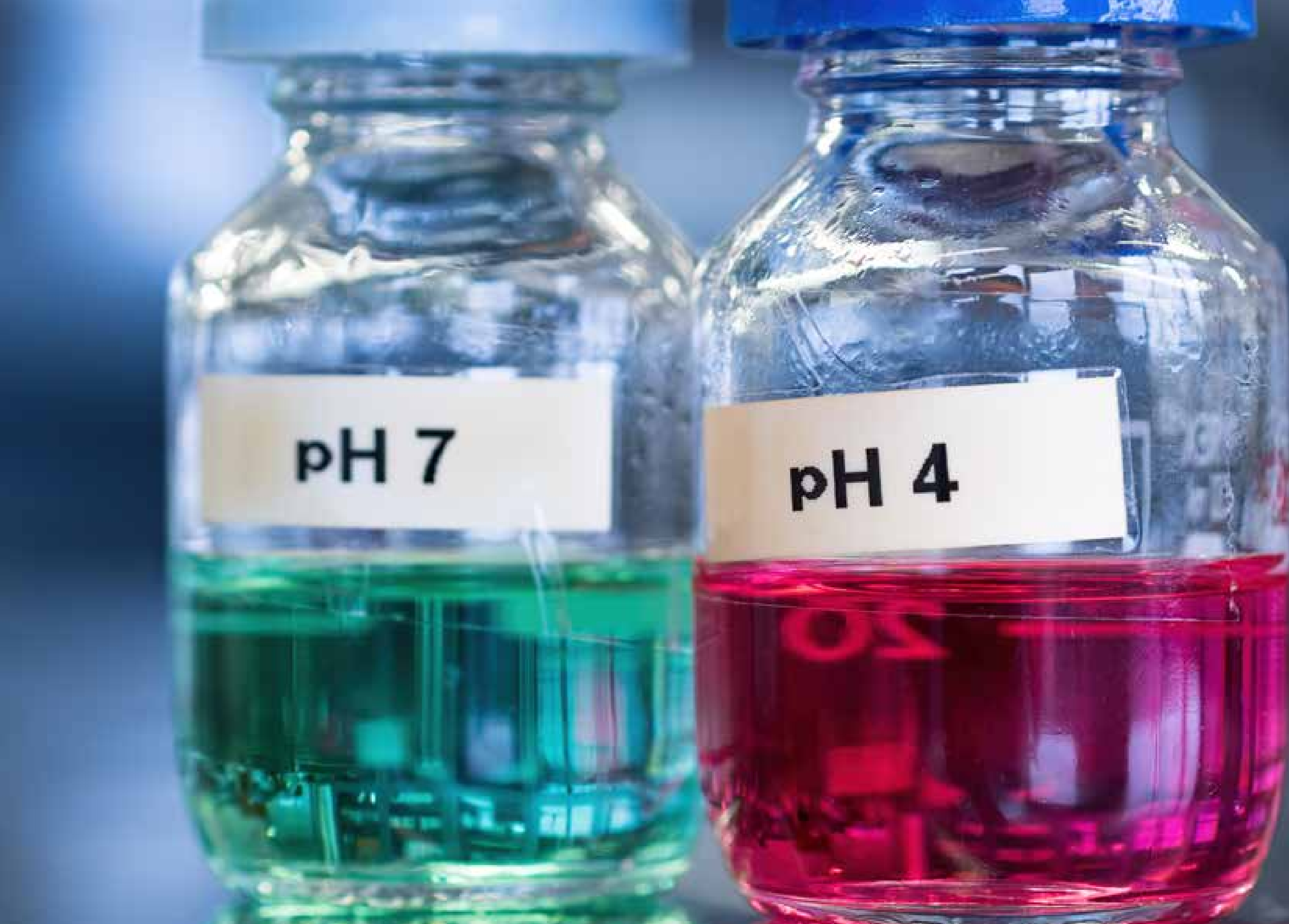

Virtual Chemistry

Using the PhET pH scale simulation and the 5E Model to enhance students' pH understanding

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Educational researchers have long advocated for the integration of computer simulations (sims) in science courses, citing the positive effects these tools have on students' science conceptual comprehension (Develaki 2017; Hannafin, West, and Shepard 2009; Lamb et al. 2011). In fact, Liao (2007) investigated the learning differences between students taught with computer simulations and those taught with traditional instructional methods, and found that computer-simulated instruction had a greater positive impact on student learning than did traditional instruction. Conceptual computer simulations offer the following advantages:

- Extend students' understandings of a concept by allowing them to modify variables and see immediate feedback (Hannel and Cuevas 2018);
- Offer students practical experience in which they can apply their scientific knowledge outside of a laboratory setting (de Jong 2006);
- Are interactive, allowing students to become immersed in an investigation resulting in greater learning gains (Kim 2006);
- Allow students to visualize and interact with invisible and/or abstract concepts such as molecular and atomic models, atomic bonding, etc.

In this article, a pH scale simulation created by PhET (Physics Educational Technology) Interactive Simulations at the University of Colorado Boulder (UCB) (Adams et al. 2008) will be discussed as a means to extend students' pH/acid/base conceptual understandings (see "On the web").

Background

Computer simulations and animations began to be used in education in the mid–20th century to represent very complex or inaccessible phenomena. Today, many of these computer sims and animations are interactive, making them particularly useful to students of chemistry (Moore, Herzog, and Perkins 2013). PhET, initiated by Nobel Laureate Carl Wiemann, began as the Physics Education Technology Project at UCB and initially included only physics-related simulations, but has since evolved to include simulations related to mathematics, biology, chemistry, and Earth science. Wiemann's aim was to advance science and mathematics pedagogy by creating computer simulations aligned with standards and vetted by educational researchers (Perkins, Loeblein, and Dessau 2010).

PhET contains 127 interactive sims free for public use, 30 of which are related to chemistry. PhET sims are utilized by the K–12 educational community and university faculty to encourage students to learn about complex scientific processes through exploration of and interaction with the sims. The strengths of these simulations include their ability to make abstract concepts concrete (such as the Molecule Shapes simulation that allows students to easily visualize and manipulate three-dimensional models of molecules); their inclusion of immediate, dynamic feedback (such as solution color changes); their intuitive nature (allows students to concentrate on conceptual understanding rather than how to work the simulation); their embedded, implicit scaffolding that allows students to proceed through a simulation with little guidance; their connections to authentic, real-world experiences; and their game-like, challenging designs (Perkins, Loeblein, and Dessau, 2010).

FIGURE 1

Micro screen box, pH scale simulation.

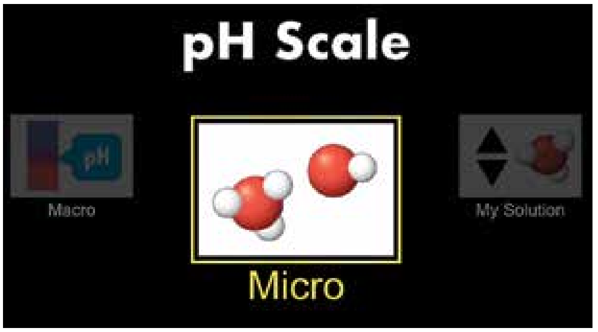

IMAGE BY PHET INTERACTIVE SIMULATIONS AND USED WITH PERMISSION.

FIGURE 2

Micro screen, pH scale simulation.

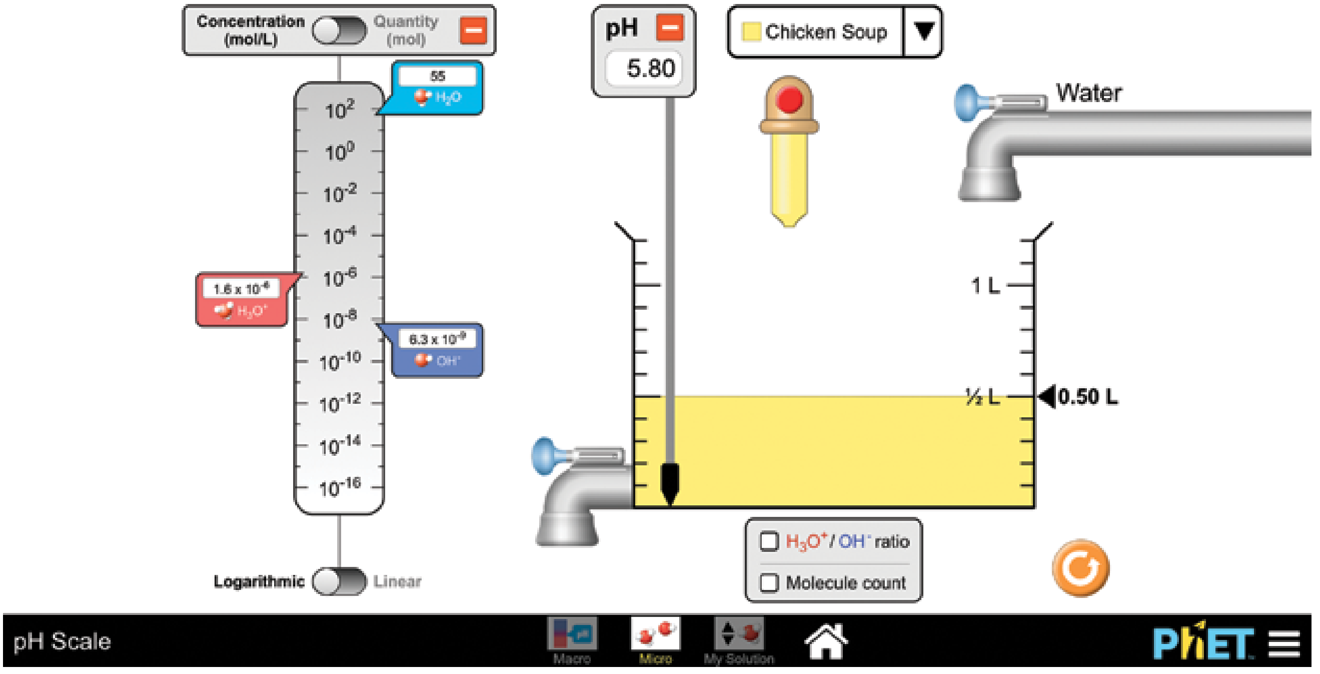

IMAGE BY PHET INTERACTIVE SIMULATIONS AND USED WITH PERMISSION.

Sample 5E lesson plan using the PhET Ph scale simulation

Engage

Safety note: Each student should be wearing chemical-splash goggles during this demonstration. To generate interest and pique students' curiosity about pH, the teacher conducts a pH Rainbow Tube demonstration (Flinn Scientific 2015). Directions for the full demonstration, including chemical preparations are available at Flinn Scientific (see "On the Web"). Prior to the demonstration, the teacher should obtain a demonstration tube (with stoppers on each end) and fill it with a dilute solution of universal indicator (green in color), within 3–4 cm of the top of the tube. When students and teacher are ready for the demonstration, the teacher removes one of the tube's stoppers and adds two drops of 0.1 M hydrochloric acid solution to the indicator in the tube. Then the teacher reseals the tube with the rubber stopper and, holding the tube at each end, inverts it, allowing students to observe the colors produced.

Next, the teacher removes a stopper and adds two drops of 0.1 M sodium hydroxide solution to the tube. The stopper is replaced and once again the teacher inverts the tube, allowing students to view the rainbow of indicator colors produced, representing the range of pH, where red represents acids of pH ~2–4; orange represents acids of pH ~5; green represents acids of pH ~6–7; blue represents bases (pH ~9); while purple represents bases (pH >10). During the demonstration, the teacher should describe what she is doing to make sure the students follow the procedure.

Explore

The pH scale screen option provided by PhET utilized in this investigation is the Micro screen, which involves the exploration of quantitative pH elements to include H_3O^+ and OH^- ion concentrations. Students are placed in groups of 3–4, with each group having access to a computer. Each group should access the PhET website's pH scale simulation (see "On the web") and click on the Micro screen box (see Figure 1).

Each group takes 5–10 minutes to freely explore the simulation with no direction (Moore, Herzog, and Perkins 2013; Podolefsky, Rehn, and Perkins 2013). In keeping with the tenets of inquiry-based learning, no procedural directions (recipes) should be provided (Chamberlain et al. 2014). During the free investigation time, students using the Micro screen (Figure 2) will see a beaker in the center of the viewing area into which sample substances to be investigated will be placed. Above the beaker is a drop box that allows for the selection of 11 different common substances (from battery acid to drain cleaner) with varying pH values.

TABLE 1

Sample substances' pH values from most acidic to most basic.

Sample Substance Name	pH

FIGURE 3

H_3O^+/OH^- ratio box, pH scale simulation.

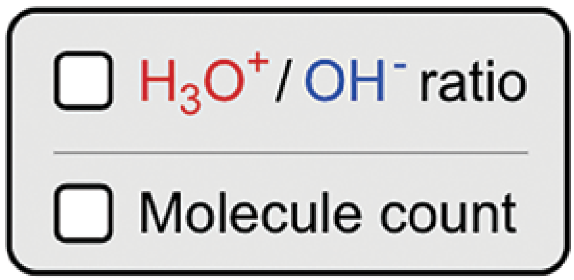

IMAGE BY PHET INTERACTIVE SIMULATIONS AND USED WITH PERMISSION.

FIGURE 4

Example clicker question for use with pH scale lab simulation.

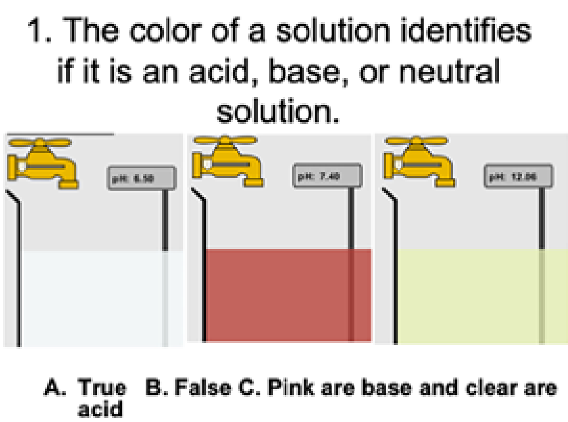

IMAGE BY PHET INTERACTIVE SIMULATIONS AND USED WITH PERMISSION.

Clicking and holding the eyedropper icon will cause the selected liquid to enter the beaker. The pH of any liquid selected from the drop-down menu can be determined by clicking on the pH meter above the beaker. The scale on the left side of the screen can toggle between concentration (mol/L) and quantity (mol) of H_3O^+, H_2O, or OH^- by clicking and dragging its switch.

Clicking and dragging the blue handle on the faucet at the top right side of the beaker allows water to be added to the sample liquid, causing its dilution; clicking and dragging the blue handle on the faucet at the bottom left of the beaker allows the liquid to be drained from the beaker.

Clicking on H_3O^+/ OH^- ratio in the H_3O^+/ OH^- ratio/molecule count box (see Figure 3, p. 27) will reveal the H_2O, H_3O^+, or OH^- concentration of the liquid in moles/Liter, which can be useful for comparing significant pH differences. The scale can be toggled between a logarithmic or linear display, and a switch is available at the top of the scale that allows students to view either concentration (mol/L) or quantity (mol).

Once students have freely explored the sim, each group practices interacting with the sim to accomplish specific learning tasks. One such task would require students list the sample substances' pH values in rank order from most acidic to most basic (see Table 1). Students next complete a table (see Table 2) in which they list the names of the sample liquids, indicating the pH of each (determined by checking the sim's pH meter for each substance), and their respective H_3O^+ ion concentrations.

Students identify each sample's H_3O^+ ion concentration by clicking on the H_3O^+/OH^- ratio in the H_3O^+/OH^- ratio/molecule count box (see Figure 3). Once columns one, two, and three of Table 2 are completed, students determine whether or not there is a relationship between H_3O^+ concentration and pH by analyzing the values in the table. Since pH is a logarithmic scale (a change of 1 pH unit corresponds to a tenfold change in H^+ ion concentration), students apply a logarithmic calculation to each sample liquid's H_3O^+ concentration using calculators, and calculated values for each liquid are inserted in Table 1 under "log of H_3O^+ concentration."

An alternative logarithmic calculation option is to have students calculate the pH of each sample liquid by determining the negative logarithm of the liquid's H_3O^+ concentration ($pH = -\log[H_3O^+]$) and then comparing their calculated pH values and the pH values the sim assigned to each liquid.

At this point, students should be provided a concept table to implicitly guide them toward effective use of the sim. Concept tables are an effective strategy to help scaffold students' learning. In this case, the concept table serves to scaffold students' learning as they interact with the sim and is purposely designed to indirectly guide students to specific sim features, capabilities, and scenarios (Moore, Herzog, and Perkins 2013). For example, a concept table could require students to make predictions, in the form of drawings, regarding their perceptions of particulate

FIGURE 5

Example clicker question for use with pH scale lab simulation.

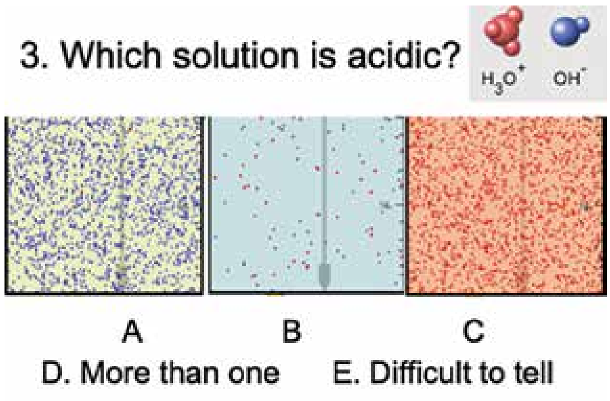

IMAGE BY PHET INTERACTIVE SIMULATIONS AND USED WITH PERMISSION.

TABLE 2

pH, H_3O^+ concentration (mol/L), Log of H_3O^+ concentration

Substance Name	pH	H_3O^+ concentration (mol/L)	Log of H_3O^+ concentration

models of three solutions with differing pH values (1 – battery acid; 6.50 – milk; and, 13 – drain cleaner) (Table 3).

Students might then be asked to select each sample substance and click the H_3O^+/ OH^- ratio/molecule count box (see Figure 3) to see the particulate model of the solution. They can draw the particulate model produced by the sim next to their own in the concept table and indicate discrepancies between the two drawings (if any) in the last box.

Once students have adequate practice interacting with the simulation by completing Tables 1 and 2, they can now be assigned one or more open-ended challenges to be solved via interaction with the sim. Possible challenge questions related to the pH scale simulation (Micro screen) include the following:

- Describe two different ways you could fill the beaker with a solution with a pH of 8.0;
- If pH values above or below 7.0 are usually considered incompatible with life, how does the stomach maintain its acidic environment (pH ~ 1–2); and
- You have been assigned the task of unstopping 13 toilets in the school and you have only 6 liters of drain cleaner. You would like to know if diluting the drain cleaner will change its pH, making it ineffective. How can you determine if dilution changes pH using the sim?

Explain

Explanation for the content explored in the Micro screen will involve both the students and the teacher in the co-examination of new vocabulary, definitions, and content as findings from the explorations are shared and discussed. The role of the teacher in this phase is to pose questions, guiding students to reflect on their experience during the Exploration and make meaning of the new pH related information. The teacher could ask students to share the pH values for each sample liquid, the samples' respective H_3O^+ ion concentrations, and each sample's log of H_3O^+ concentration value on a large table reproduced on the board identical to Table 1. Students could compare their findings against those placed in the table by their classmates' and discuss possible reasons for errors.

Following the students' completion of the table on the board, the teacher now turns to addressing the content she wants students to know related to the pH scale, including related vocabulary terms and their definitions. Content related to pH might include: acid and base definitions; acids and the hydrogen ion; neutralization; dissociation of water; the ion product of water; neutral solutions; the pH scale; determining pH; pH indicators; universal indicators; conjugate acid-base pairs; strong and weak acids; strong and weak bases; and criteria of acidic, basic, and neutral solutions.

TABLE 3

Concept table for use with pH simulation.

A. Draw your predicted idea of how a solution with a pH of 1 will look at the particulate level.
B. Draw your predicted idea of what a solution with a pH of 7 will look at the particulate level.
C. Draw your predicted idea of what a solution with a pH of 14 will look at the particulate level.
D. Compare your drawing with the sim's representation, and share any discrepancies seen.

Solution with pH = 7		
My Predicted Drawing	Sim's Representation	Discrepancies
Solution with pH = 0		
My Predicted Drawing	Sim's Representation	Discrepancies
Solution with pH = 14		
My Predicted Drawing	Sim's Representation	Discrepancies

Elaborate

Students will extend their knowledge gained in this lesson to agriculture by measuring a soil sample's pH, learning how it affects nutrient uptake by plants, and deciding whether or not the soil should be modified. This lesson is a modified lesson created by the California Department of Food and Agriculture's (CDFA) Fertilizer Research and Education Program (FREP) (Bottoms and Emerson 2011) (see "On the Web"). Students will act as agronomists and test the pH of farmer-supplied soil samples from three farms using three differing pH testing methods (pH test kit, pH paper, electronic pH meter) and will provide each farmer with their soil's pH and possible soil modification recommendations.

Evaluate

A summative assessment of this lesson can be created using clicker questions and PhET screenshots. Loeblein (2015), a physics teacher at Evergreen High School in Evergreen, Colorado, regularly makes use of a number of PhET sims and has created clicker questions, each with an illustration, that are available for free at the PhET website. The clicker assessment should take place directly after completion of sim. Figures 4 (p. 27) and 5 (p. 29) demonstrate two of Loeblein's sample clicker questions.

Resources for teachers

PhET simulations come with a variety of teacher resources including sample learning goals; teacher-created activities for use with the simulations; and "Teacher Tips" for each simulation that address difficulties students might encounter, explain nonobvious controls, and outline modeling assumptions inherent in each simulation. PhET also provides a comprehensive resource guide for effectively incorporating clicker use with the simulations. In addition, PhET simulations in general lend themselves quite well to a *Next Generation Science Standards* (*NGSS*) curriculum because the *NGSS* recommend the use of modeling in science as early as the third grade continuing through middle school and high school. An explanation of *NGSS* alignment can be found in the "Teacher Resources" section for most PhET simulations (Perkins, Loeblein, and Dessau 2010). ■

ON THE WEB

Flinn Scientific, Chem Fax: pH Rainbow Tube Demonstration: *www.flinnsci.com/api/library/Download/0f1d8a1f0b454ccea141dc73b705da02*

Chemistry, Fertilizer, and the Environment. California Department of Food and Agriculture's (CDFA) Fertilizer Research and Education Program (FREP): *www.agclassroom.org/teacher/matrix/lessonplan.cfm?lpid=317*

The PhET Interactive Simulations Project. *http://phet.colorado.edu*

PhET website's pH scale simulation: *https://phet.colorado.edu/en/simulation/ph-scale*

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